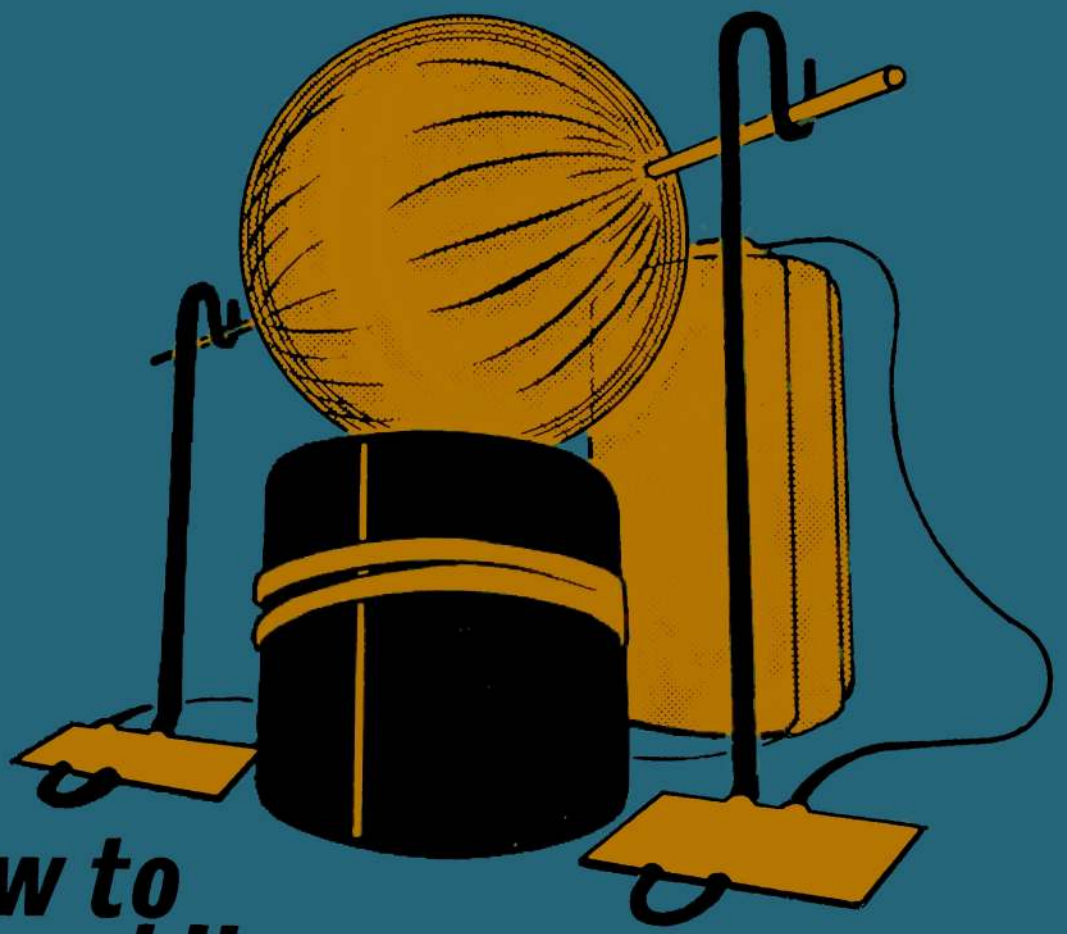
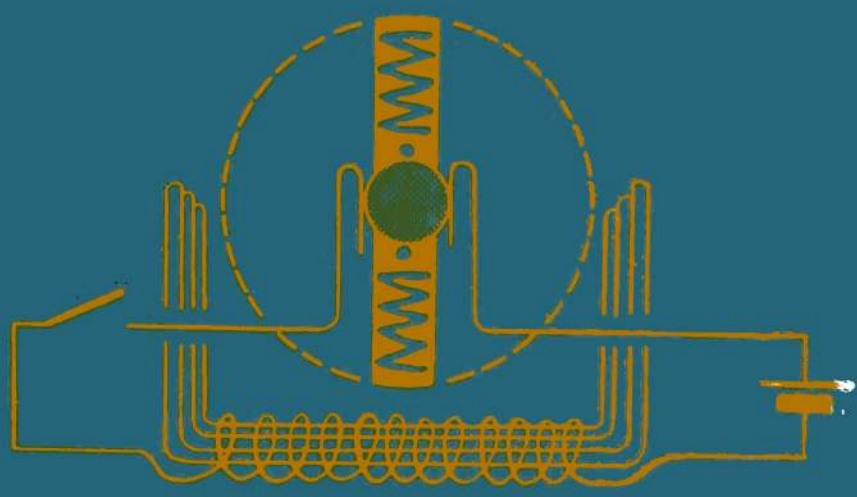
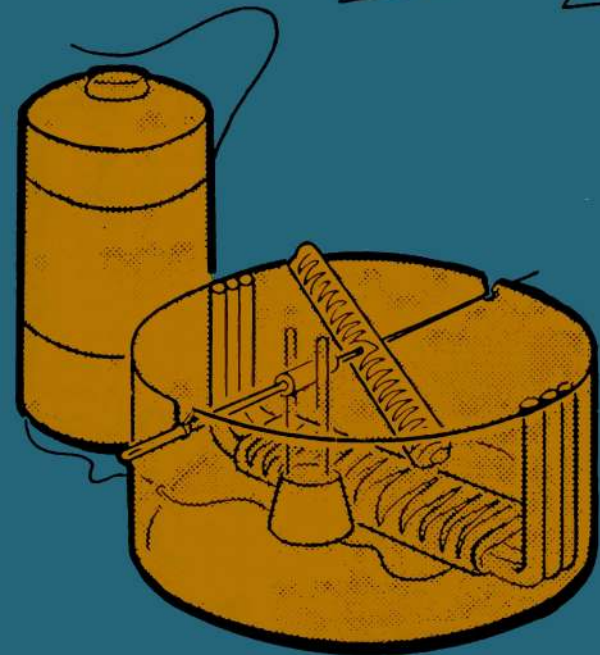




*How to
Make and Use*
Electric Motors
AL G. RENNER



*How to
Make and Use*
Electric Motors
AL G. RENNER

Electric motors come in a vast range of sizes, but the three in this book can be built by the reader. The parts are simple and inexpensive, and the instructions are clear for building the Mini, Midi, and Maxi Motors. The author also provides a number of intriguing experiments that include taking the motors apart and interchanging them.

12216

Jacket design by
JAMES E. BARRY


\$4.97
This is a
PUTNAM
Guaranteed
Binding

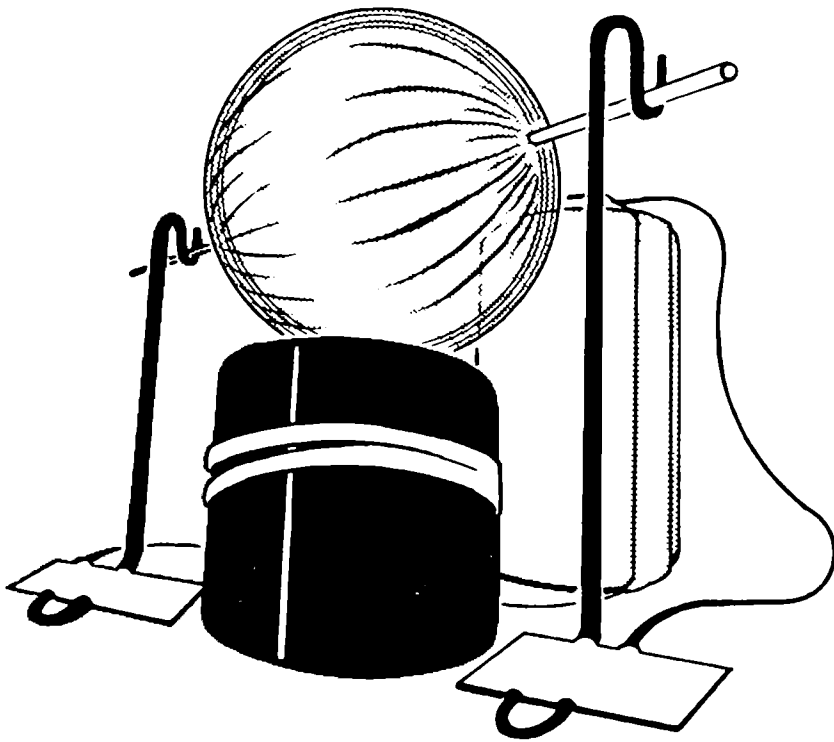
How to Make and Use Electric Motors

About the Book

Learning is fun for the young scientist or engineer. In this book author and science teacher Al G. Renner teaches one to build and use three basic electric motors: the Mini, the Midi, and the Maxi. Using simple parts and following clear instructions, the reader-builder is encouraged to take them apart and change and interchange them. From experimenting comes skill and knowledge in basic electricity.

How to Make and Use **Electric Motors**

AL G. RENNER



G. P. Putnam's Sons • New York

Copyright © 1974 by Al G. Renner
All rights reserved. Published simultaneously in
Canada by Longman Canada Limited, Toronto.

SBN: GB-399-60858-3

SBN: TR-399-20369-9

Library of Congress Catalog Card Number: 73-77421

PRINTED IN THE UNITED STATES OF AMERICA

10 up

Contents

Introduction 7

1. How Do Magnets Work? 12

2. The Mini Motor 18

3. The Midi Motor 53

4. The Maxi Motor 85

5. The Super Motor 124

Index 126

SCIENCE PROJECT BOOKS FROM PUTNAM

HOW TO MAKE AND USE A MICROLAB

by Al G. Renner

YOUR SCIENCE FAIR PROJECT

by William Moore

HERE IS YOUR HOBBY: SCIENCE EQUIPMENT

*Easy-to-make items for
the home science laboratory*

by William Moore

HOW TO MAKE AND USE ELECTRIC MOTORS

by Al G. Renner

Introduction

This book has been designed to give you a great variety of experiences as you build electric motors. You will be helped in making three basic motors: the Mini Motor, the Midi Motor, and the Maxi Motor. After building each of these models, you will be encouraged to take them apart, to change them, and to interchange them in order to experiment and to learn more about them. The final chapter of this book will invite you to use all your newly gained experience and knowledge to design a Super Motor, which can contain all the best features, the best properties, and the best conditions that you can put together in your own best motor.

Each of the basic motors is designed to be taken apart easily. They were planned as experimental models to be changed again and again rather than to be put on the mantel as finished display models. The motors, of course, can be made more permanent when you have concluded your experimenting.

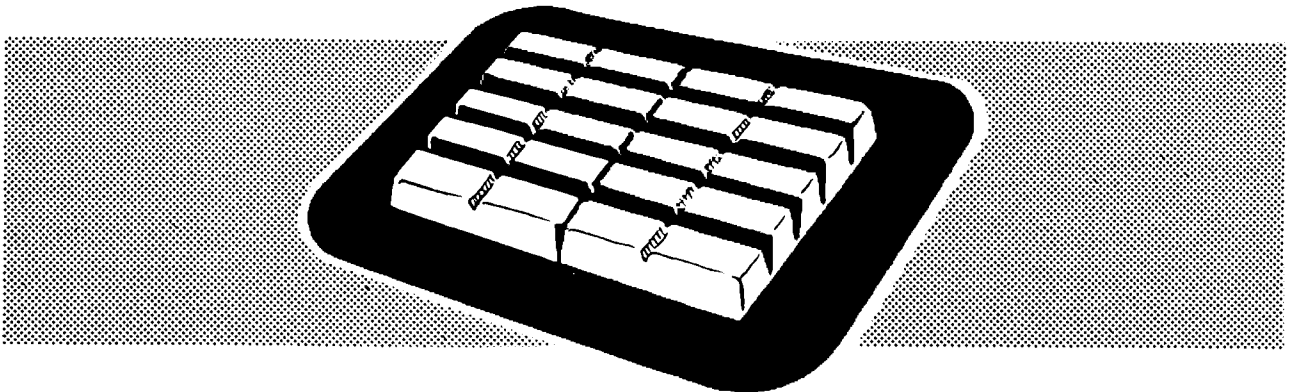
You will be given a few suggestions on each page for experimenting just to get you started. It is hoped that you will generate some ideas for experimental changes of your own as soon as you can. Always be sure to test these ideas by predicting what will happen to each motor before you start spinning it.

Collect Some Magnets First

Small electric motors are usually made with two magnets. One magnet is stationary. It is named the stator or the field magnet. The other magnet spins. It is called the rotor or the armature. So, to know about electric motors, you certainly must be able to use and to understand magnets.

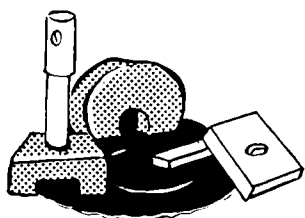
All the motors in this book can be made with the small, most inexpensive Alnico bar magnets. They can be purchased at almost any hardware, variety, or toy store. Sometimes they are called hot-pad magnets by the clerks in these stores. Ten of these little magnets are often sold on an iron pad. Buy all ten of them if you can.

Also, collect any other kinds of magnets that you can find. Make trades with your friends for new kinds of magnets. Search the surplus stores. Make friends at radio and television repair shops. Once you start collecting magnets, you will never stop. They will intrigue you, and they will be working for you the rest of your life.

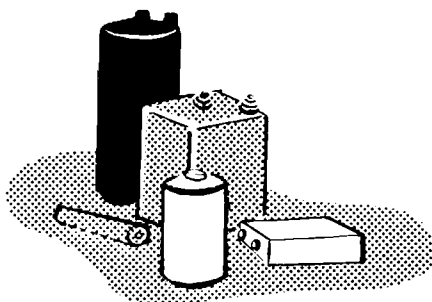


Alnico hot-pad magnets

Other Materials Which You Will Need



Other kinds of magnets



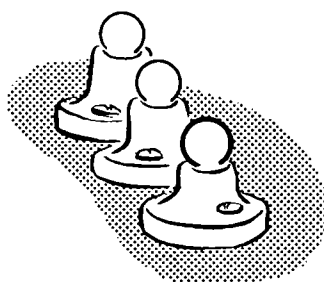
Several kinds of dry cells



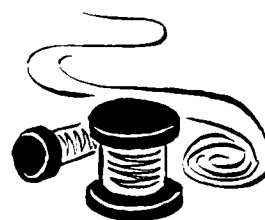
Plastic medicine bottles



Compasses



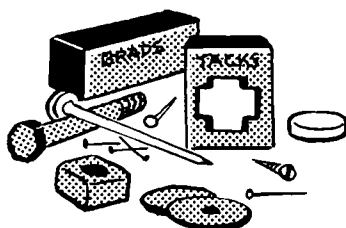
Miniature lamps



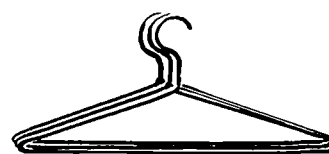
Lots of wire



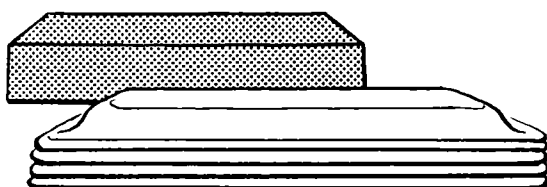
Tape and quick-dry glue



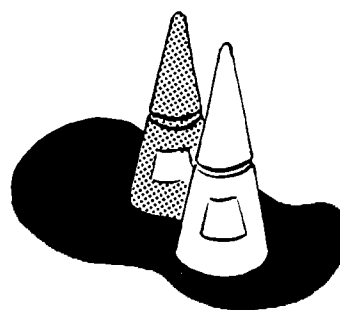
Nails, bolts, nuts, and screws



Wire coat hangers

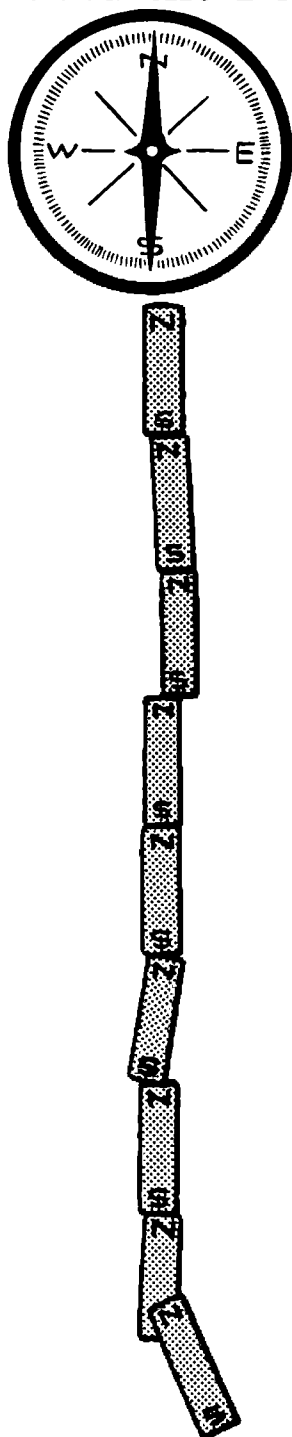


Foam blocks and trays



Fingernail enamel

Find the Polarity of Your Magnets



Put your compass over the drawing on the left. Turn this book with the drawing until the needle of the compass is under your compass needle. The title of this page then should be facing the north side of your house.

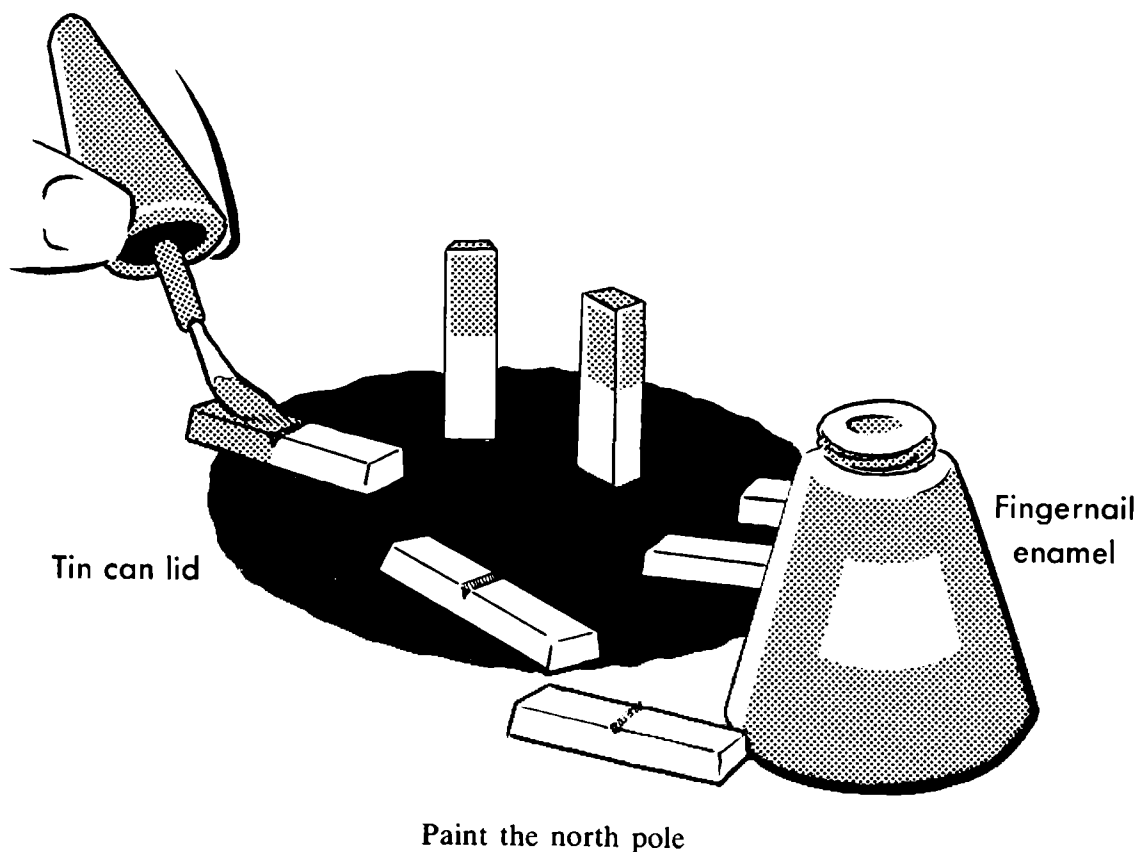
The north-seeking pole of one of your Alnico magnets will be attracted to the south pole of the compass needle and will hold it steady. Put this magnet in place on the drawing.

All your other magnets will obey the same rule: "Opposite poles attract, and like poles repel." As you place each magnet in line, it will either stick or spin to indicate its polarity to you. Leave the magnets sticking together in line until you are ready to mark them as suggested on the next page.

Mark Your Magnets

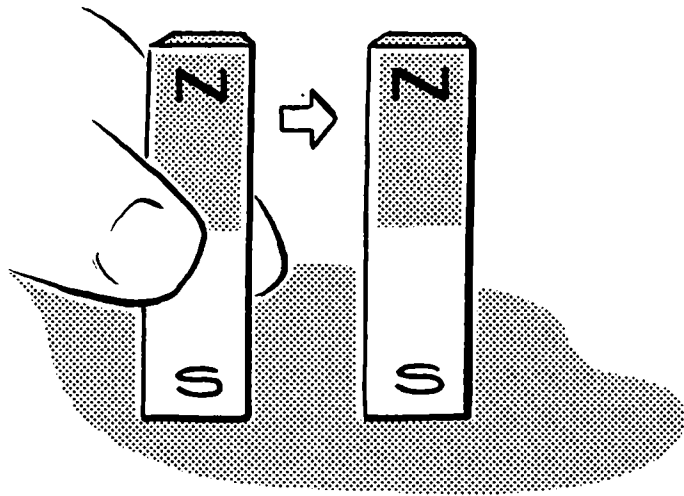
Your electric motors will be easier to make and to understand if you mark your magnets before you start. Paint the north-seeking end of each magnet. Red is a good color, and fingernail enamel is a quick-drying and easy-to-use paint.

Put a newspaper down first to protect your table. Then put the magnets on a tin can lid at the edge of the table. Fasten each magnet over the edge of the metal lid for painting. After you have marked the north pole, stand it on the far side of the metal lid to dry. Magnetism will hold it in place while drying.



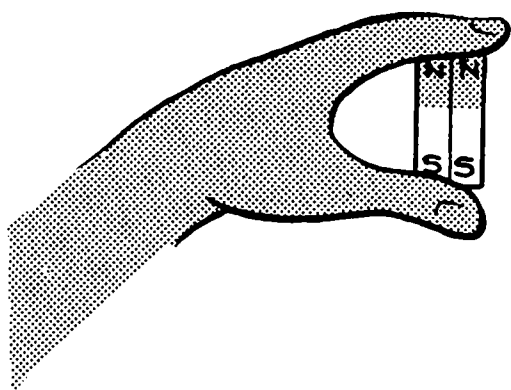
1

How Do Magnets Work?



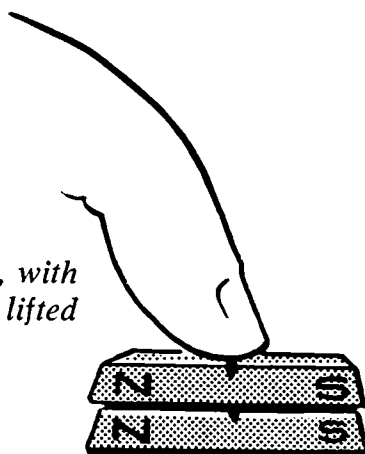
The Magnets Will Tell You

How do magnets work? Just ask them. They will tell you. When you have problems with natural things, nature will tell you what you want to know. All you have to do is learn to ask specific questions. Specific questions are definite, explicit, and precise. They usually are questions about a particular condition in scientific experimenting. Try asking these specific questions of your magnets under these conditions. Nature will tell you how the magnets really work. Nature will give you data which is true information.

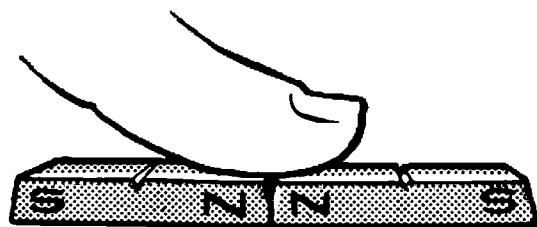


If I held two magnets, with like poles together, and slowly opened my fingertips. . . .

If I held one magnet on another, with like poles together, and suddenly lifted my finger. . . .



If I held two magnets together in end-to-end position, with like poles together, and slowly rolled my fingertip backward. . . .



Magnets tell the truth

Experiment to Learn More

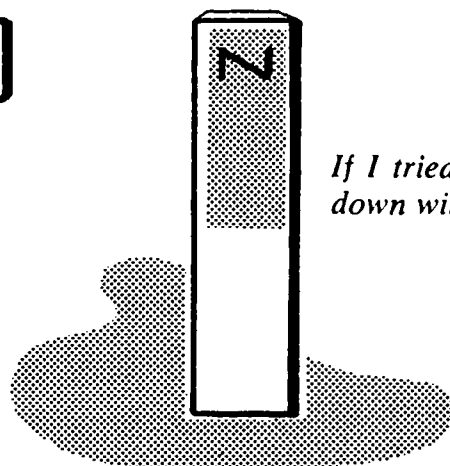
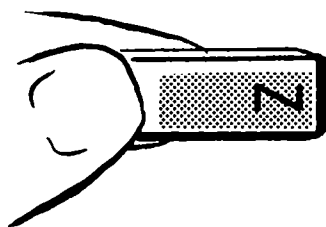
An experiment is a change which you make in a problem situation to learn more about it. Does the change make a difference? If it does, can you make it happen again? If you can make your magnets do many different things at your command, you will know much more about them. You will be changing things about your magnets for two reasons.

First, you will change things to gather data. Data are the facts, the true information, about what magnets really do. You will say to yourself, "If I changed (*usually a condition*), what would happen?" This is called an if-would data-seeking inquiry.

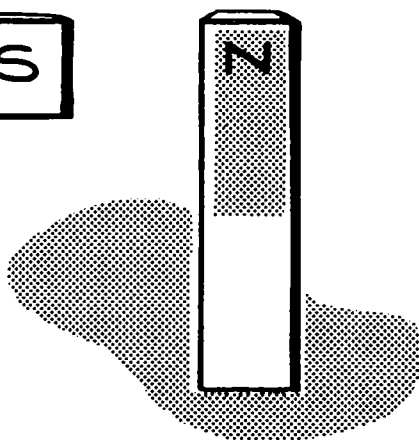
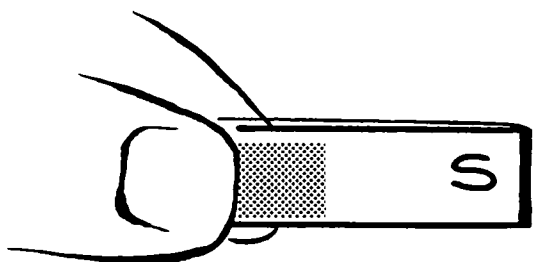
Second, you will change things to test your ideas about how the magnets will work in new situations. You will change a variable and make a prediction about what you think will happen. When you want to test your own ideas, you will probably say to yourself, "If I changed (*usually a condition*), then I predict that the magnets will not repel or push apart." You will be testing your own understanding when you make an if-then inquiry.

Why don't you start now with your own experimenting? This book will suggest a few changes on each page to help you get started. And then it will encourage you to design more inquiries and more experiments of your own.

Make Changes to Experiment

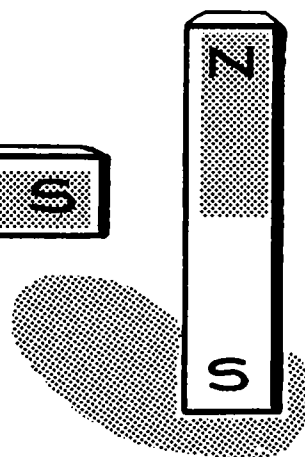
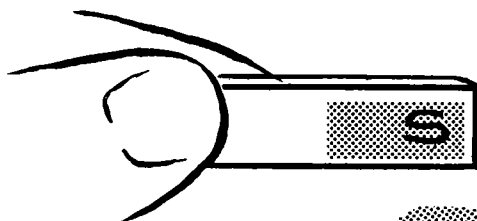


If I tried to push the standing magnet down without touching it. . . .



If I changed the poles of the magnet in hand and tried to push the other down. . . .

If I pushed slowly toward the middle of the standing magnet. . . .



Purposeful changes produce experiments

What Do You Know Now?

How do magnets work? Under each new condition they will work differently. Probably you have noticed little differences already. Can you make these differences happen again? If you can make your magnets perform their different actions as you wish, you are beginning to understand them, even though you may not be able to explain their actions in technical terms.

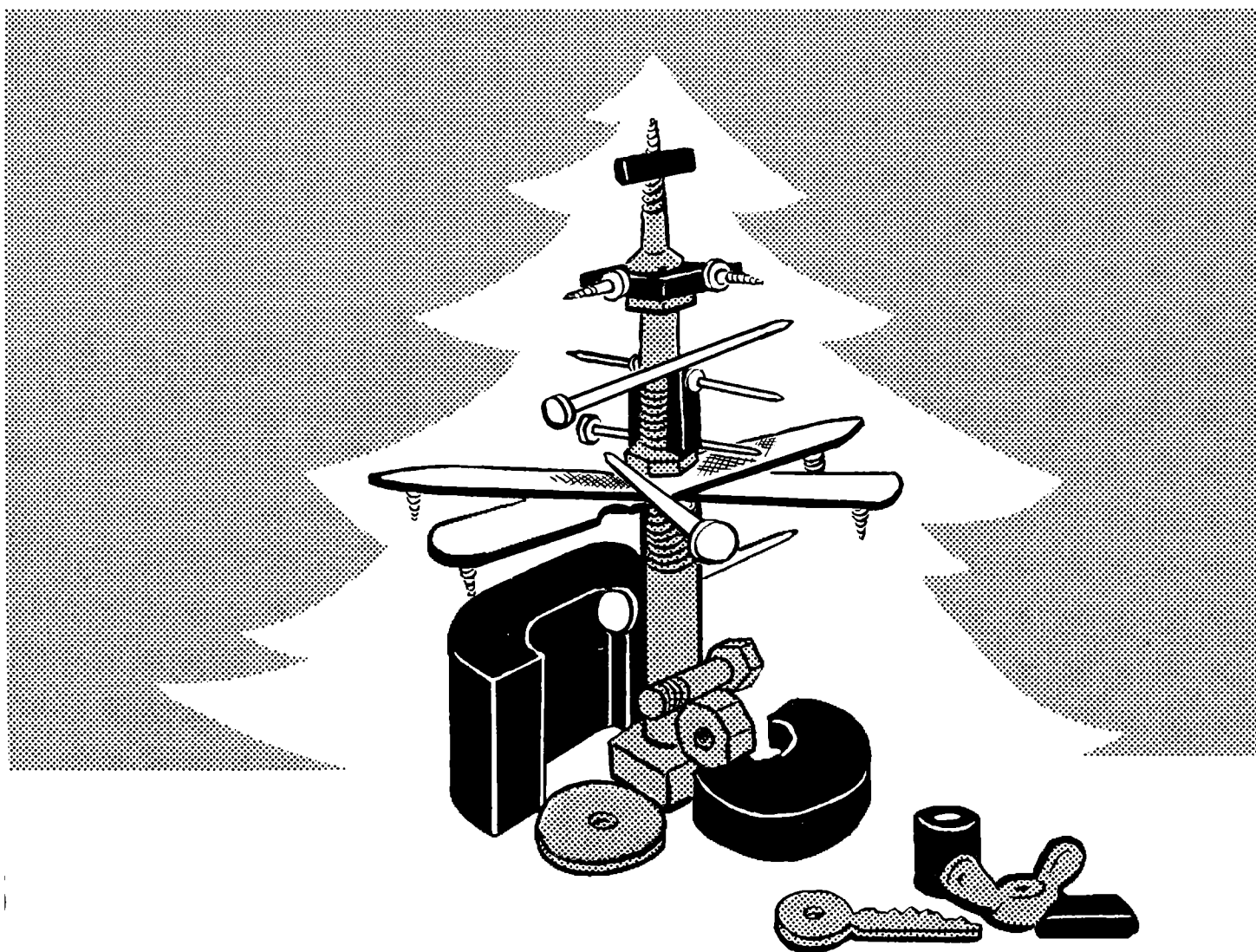
You can test your understanding best with predictions. Predicting is describing what you think will happen before each new experiment is begun. Prediction is the most powerful test of human ideas. Don't be afraid to be wrong with your predictions. You will find yourself closer to the truth each time that you try.

This book will help you make very definite predictions. The following pages will show many examples of how to start experiments. The finish of the experiments is not shown. This was done so that you can develop and test your own ideas about how the motors work. Sketch each experiment on a page. Make very definite predictions about how the experiment will progress and finish. But make your notes as brief as possible, using symbols and abbreviations as well as the sketches. Then do the experiment. Does reality match your prediction? In this way you will have a lab record of your experimenting. You will soon learn how much you really know about magnets and motors.

What Do Magnets Attract Besides Other Magnets?

Try your hand at magnetic sculpturing. Gather a collection of small objects such as a can lid, bolts, nuts, washers, nails, tacks, screws, paper clips, thumbtacks, erasers, buttons, pins, needles, coins, rings, jewelry, blocks, keys, and bottle caps.

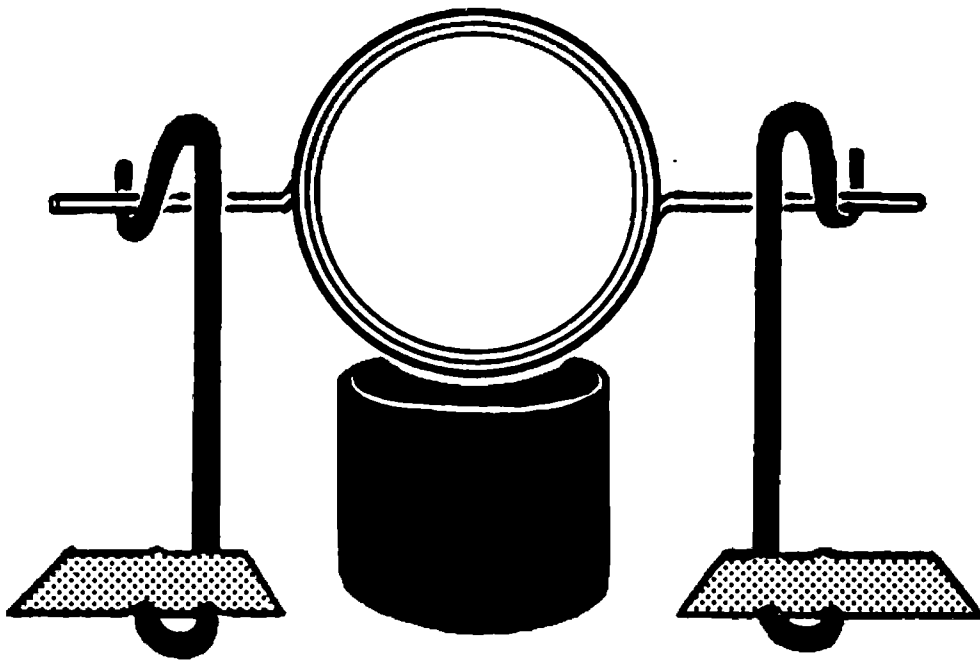
The tree shown below is just to get you started. What new design can you originate? What word classifies best all the materials which naturally took part in the magnetic sculpture?



Magnetic sculpture

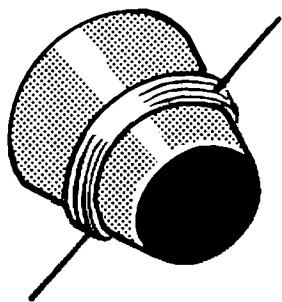
2

The Mini Motor

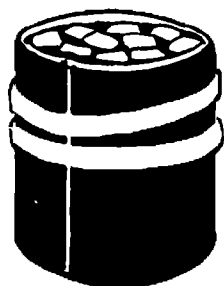


The Mini Motor has a permanent stator magnet with an electromagnetic rotor. This little motor can be made with a minimum of materials and equipment. However, it surely will help you to experiment more if you can gather a few tools together.

How the Mini Motor Is Put Together



1. Wind the rotor magnet on a small cork.

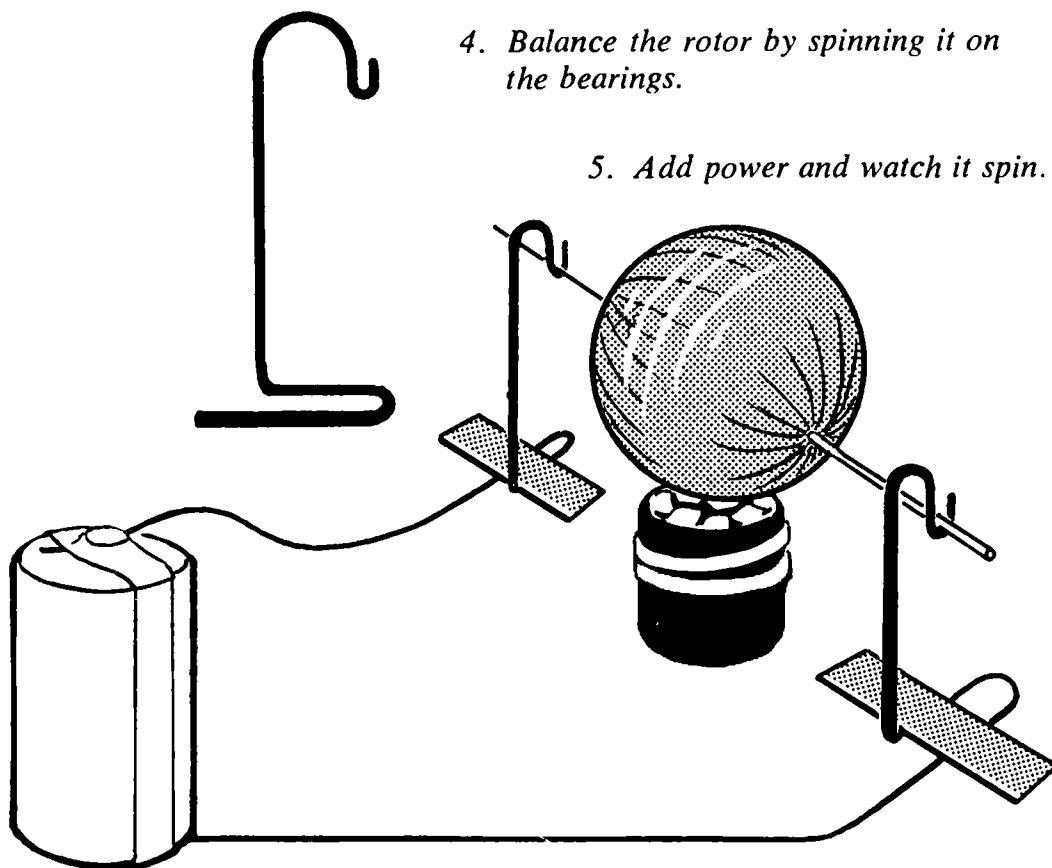


2. Assemble the stator magnet.

3. Bend the bearings and tape them to the table.

4. Balance the rotor by spinning it on the bearings.

5. Add power and watch it spin.



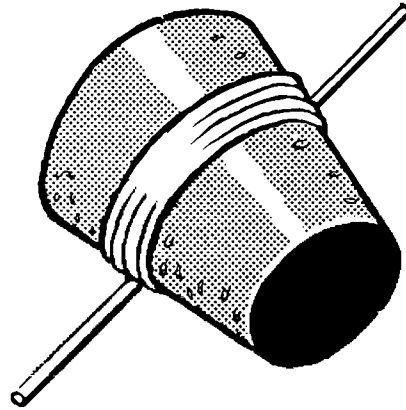
Each step will be explained on a separate page

Wind Your Rotor Coil

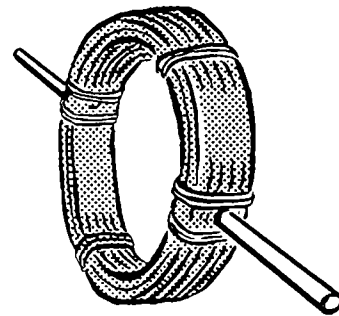
Wind about two feet of varnish-insulated copper wire around a small cork. Bend the ends out at right angles from the coil to be used as axles. Never twist the axle wires around the coil. Tie, glue, or tape the coil as shown at the right.

Remove the insulation from the axles by scraping with a sharp knife. It helps to soften the varnish first with paint remover. A small amount of paint remover can be used safely and stored in an old fingernail enamel bottle. Another way to soften the varnish is to burn it with a match.

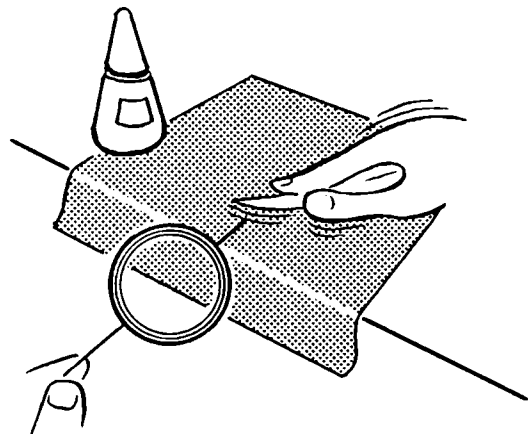
The axles of this motor must be bare, bright, and very clean because they will be part of the electrical circuit.



Bend the axles at right angles

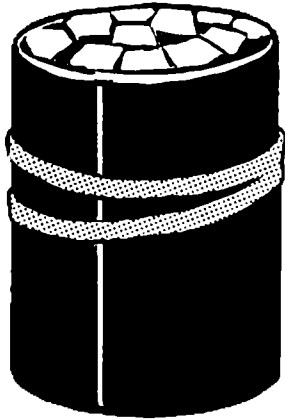


Fasten coil with thread, glue, or tape



Remove varnish insulation from the axles

Bind Your Stator or Field Coil



All north poles must face upward



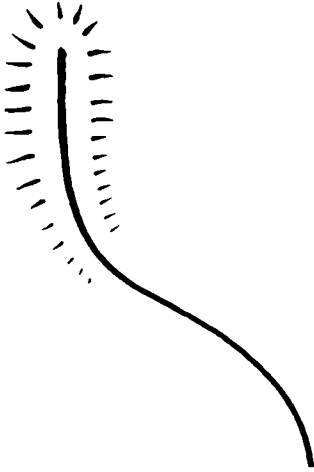
Hold all north poles in place with paper fence

The stator magnet is stationary. It is also called a field magnet. Your stator will be made of about ten small Alnico bar magnets secured together with a rubber band.

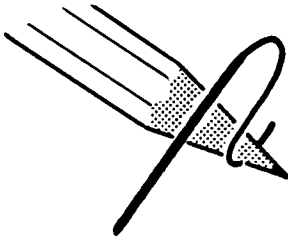
Place all the north poles so that they face upward. This is easier to say than it is to do. Bind a half dozen magnets inside a paper fence with a rubber band. Then pry open the center section to add more. Put together as many magnets as you can to make your stator as powerful as possible.

It is important to remember that all north poles must face in the same direction. This is what makes this task so hard to do.

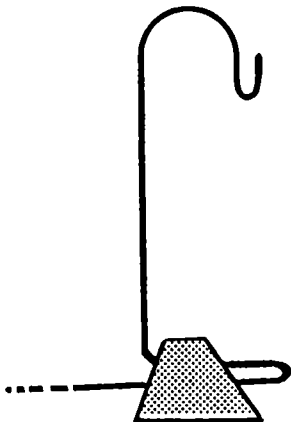
Bend the Bearings



Bearing wires must be bare, bright, and clean



Bend bearing wires with a pencil point



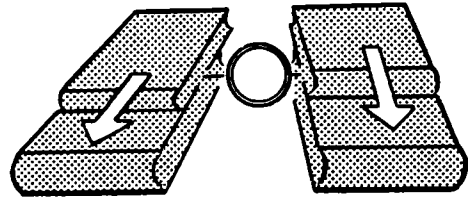
Tape bearings to the table

It is important in an experimental motor that you be able to change rotors easily. This will enable you to do much more experimenting. That is why cradle bearings are recommended throughout this book.

Scrape the varnish insulation off the ends of two 18-inch wires. Bend the shiny ends around a pencil point into an S shape. Make the bearing posts just tall enough so that the rotor coil will spin slightly above the stator magnet.

Bend the lower ends of the bearing wires into flat feet so that you can tape them to the table. The long, loose ends which come off the bearing feet will be connected to the dry cell or battery.

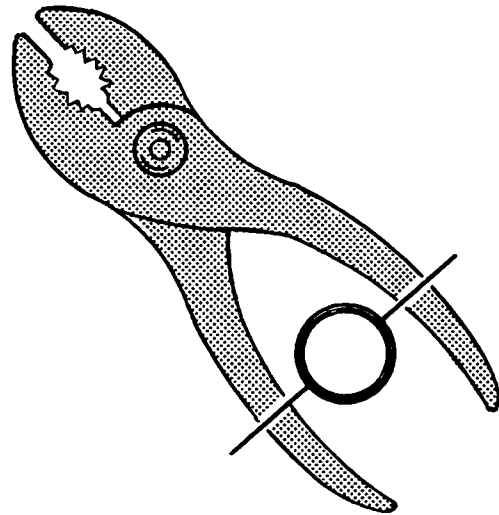
Balance the Rotor Coil



Straighten axles with books

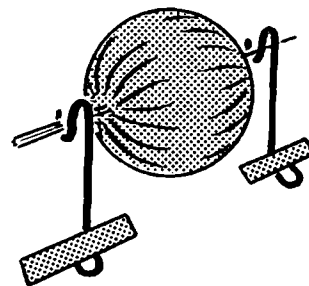
Your rotor coil must be well balanced so that it will spin effortlessly. Making a straight axle that goes through the very center of the coil is a good start. Roll the axle between book covers to straighten it most easily.

Then lay the coil across the handles of a pliers to see if it is balanced on the axle. Add drops of glue or strips of tape to the coil's lighter side.



Balance axles across handles of pliers

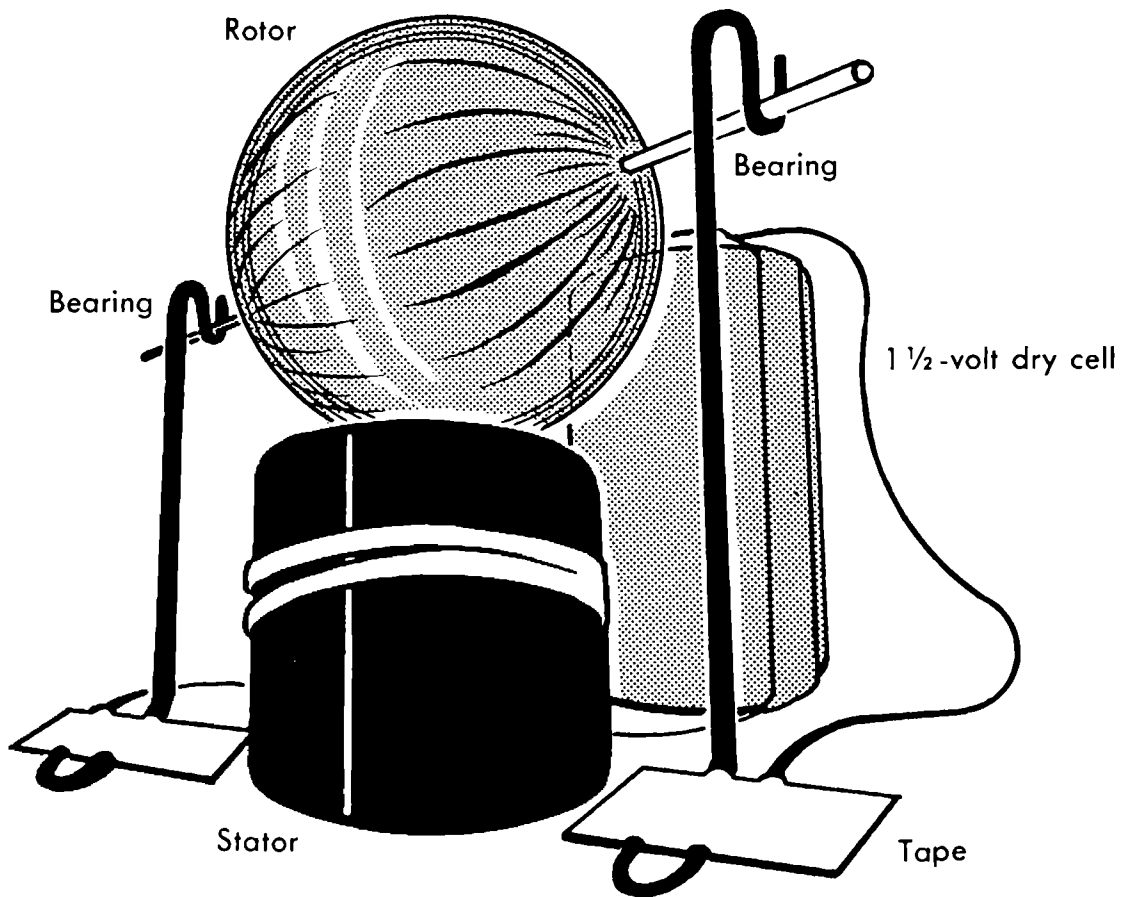
Put the rotor coil in the bearings now, and spin it with your fingertips. A double image indicates an axle out of line. Remember that balanced rotor coils are extremely important in all your motors.



Spin-test axles in the bearings

Add Power and Watch Your Mini Motor Run

This Mini Motor should run on a standard flashlight dry cell. Attach the two wires from the feet of the bearings to the two terminals of the dry cell. Hold the wires in place with a rubber band so that your hands will be free. The rotor will be your switch so that you can start or stop your motor at any time. When you first put the rotor in place, you should be able to see and even feel evidence of the magnetic interaction. Spin the rotor axle with your fingertips and watch the Mini Motor run. Now, if you experiment freely, this simple motor will teach you a great deal about magnetism and electricity.



The Mini Motor

Now It Is Time to Experiment Again

Now that you have made a motor that works, you are going to be asked to take it apart, to change it, to rearrange it, and to experiment with it. To make a motor work as you have just done is a fine accomplishment. But to make this motor work under many different conditions is an even greater achievement. This is where learning really begins.

An experiment takes place when you change something to learn more about it. What can you change about this Mini Motor now? You can change anything and everything about it. Watch for little differences that you can make happen. Can you make these happen again at your command? Some changes will make your motor run better. Some changes will not please you. But even your failures will be teaching you something about this motor. If you can make the good things happen at any time and in any combination that you want, feel good. This means that you have control of your motor and are beginning to understand it.

There follow a few suggestions for changes or experiments just to get you started. Always try to design some new experiments of your own before you turn to the next page. You will be delighted with some of the variations which you can build into these motors. Each change will teach you something new.

Change the Base

If I used a note card for the base of the motor. . . .

This would enable you to move your motor freely so that you could take it to show to your friends.

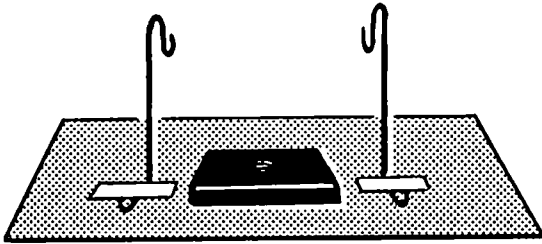
If I changed to a wooden block for a base. . . .

You could tape the bearing posts to the wooden block. Or you could double the bottom of the bearing posts and stick them into nail holes.

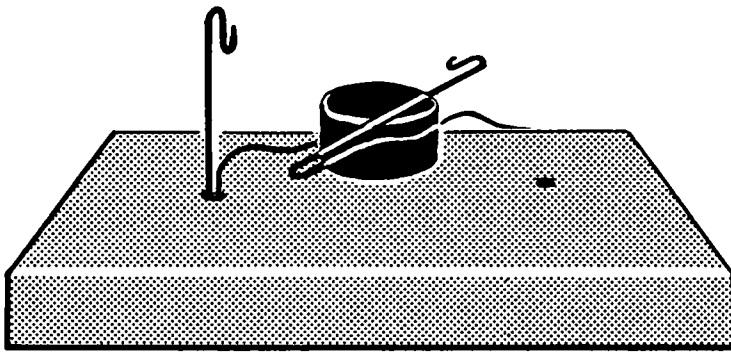
If I built my motor on several foam meat trays which have been pinned and glued together. . . .

Glue the foam trays with a water-soluble glue. Double the bottom of the bearing post wire to stick it into the foam. Try styrofoam and urethane foam blocks for bases also.

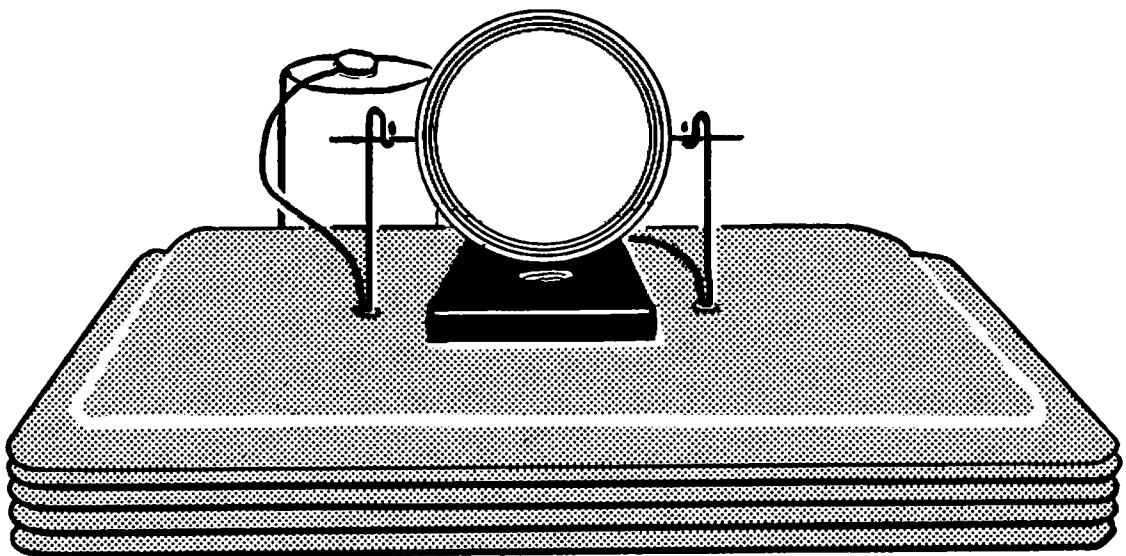
Change the Base



Note card base



Wooden block base

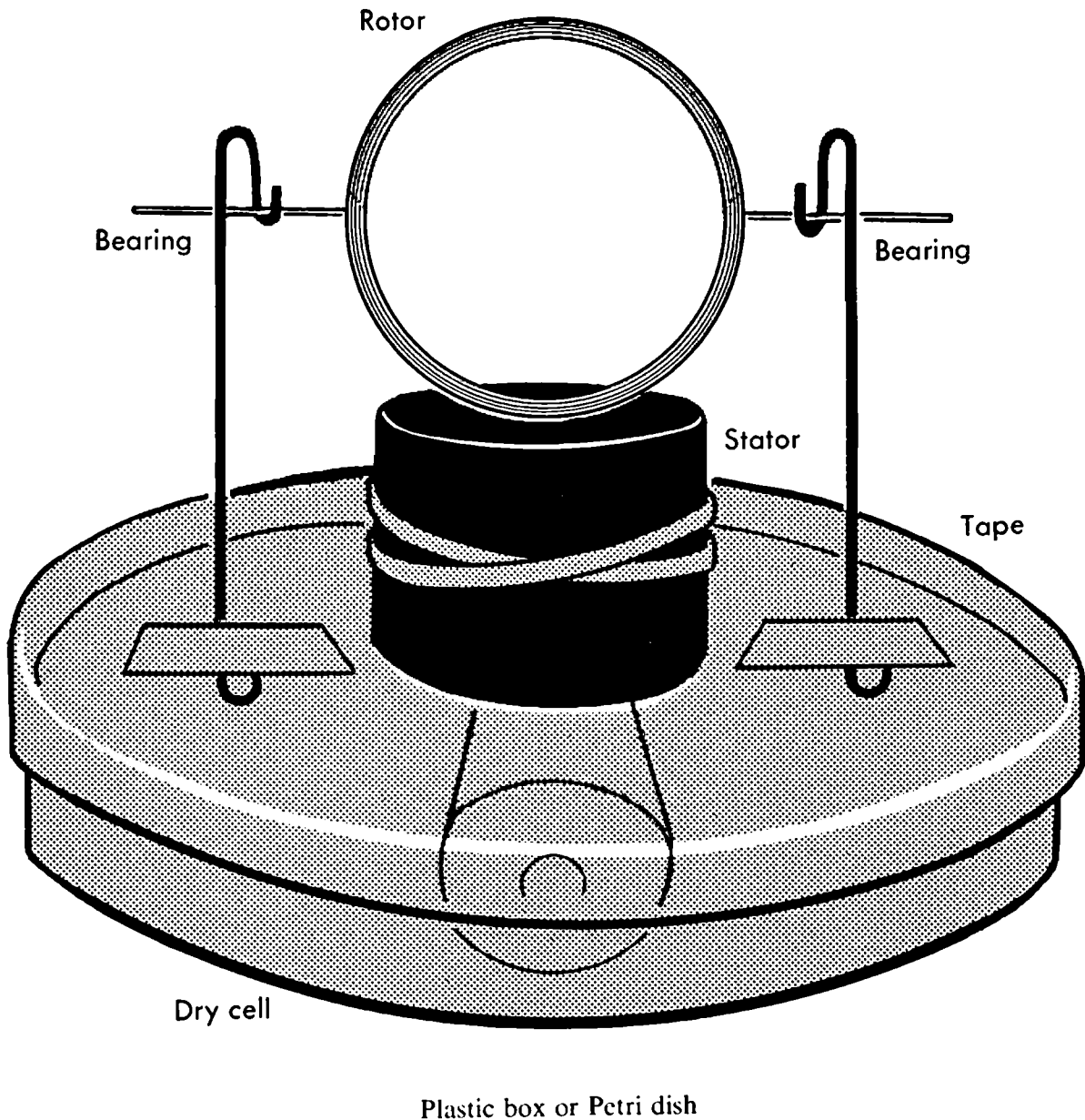


Plastic foam meat tray base

Change the Base

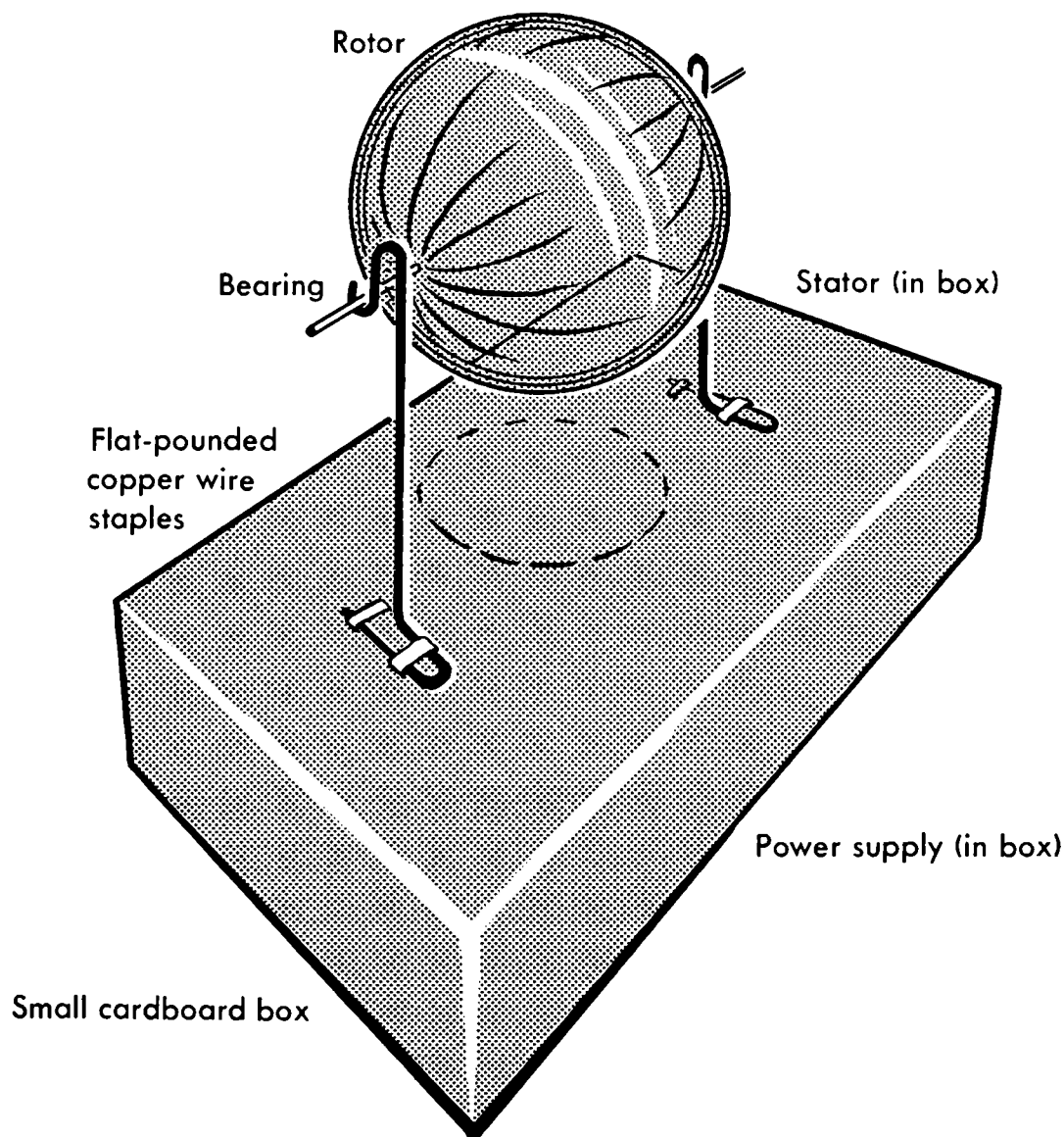
If I changed the base to a clear plastic box and built my power supply inside the box. . . .

The bearing feet can be fastened to the plastic box with clear tape. Drill holes in the plastic for the wires.



Change the Base

Hide the power supply and the stator magnet in a small, flat cardboard box and staple the bearing feet to the top. The staples can be made from copper wire which has been pounded flat. Drill holes for these staples with a very sharp knife or with the sharp corner of a razor blade.

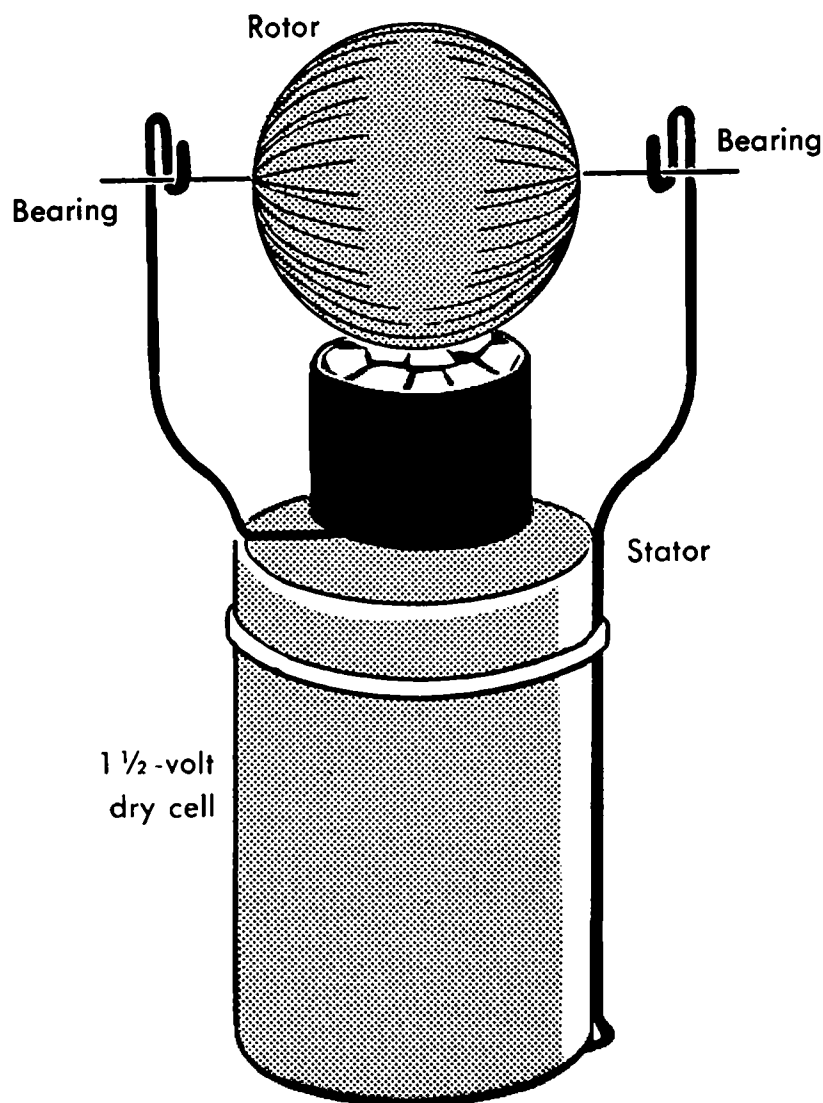


Hide power supply and stator magnet in base

Change the Base

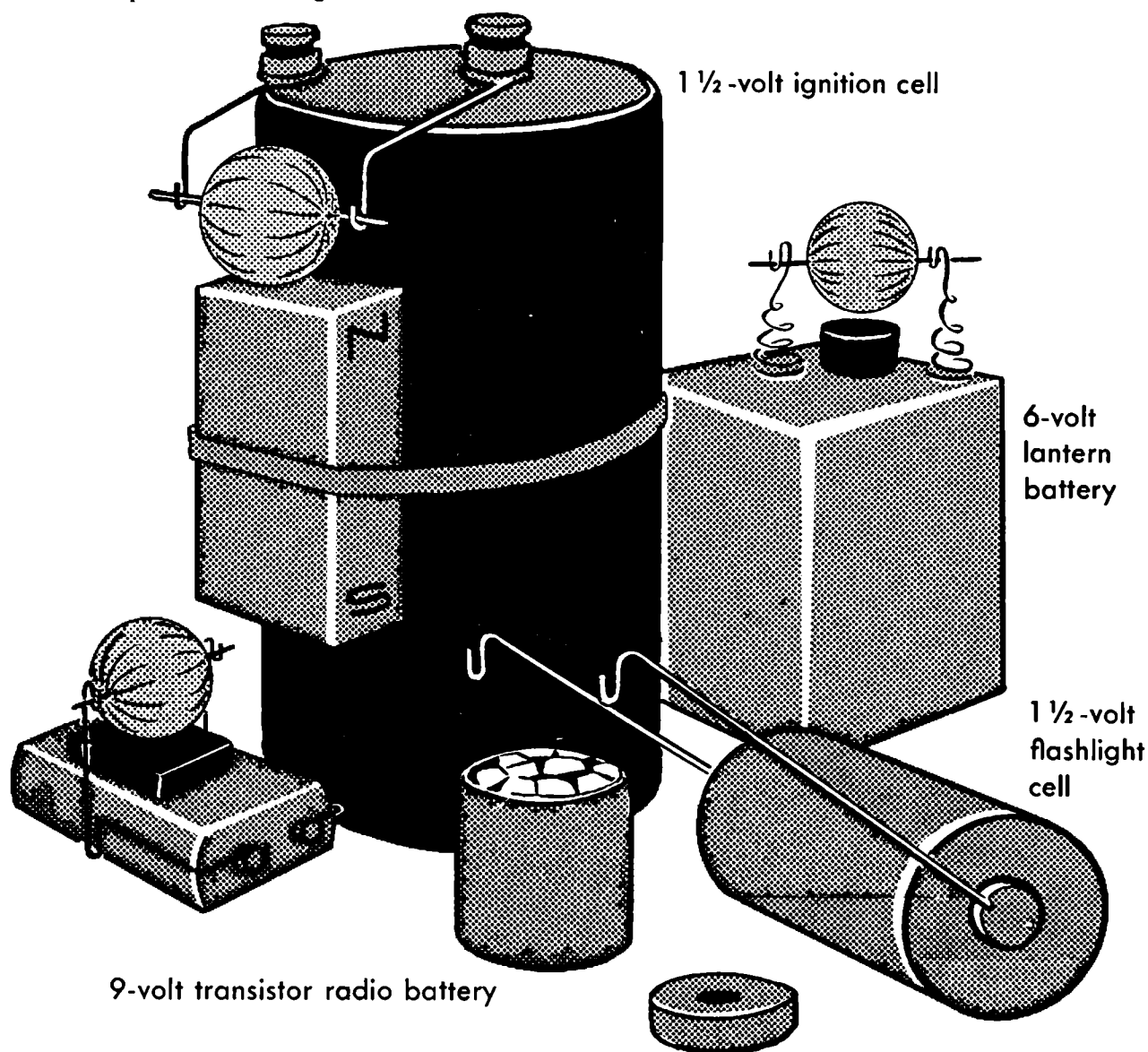
If I made the power supply the base for the motor. . . .

Soldering the terminals would be better than twisting the wires if a soldering iron is available. Be sure to insulate the stator if the terminals are close together, as on the #6 dry cell.



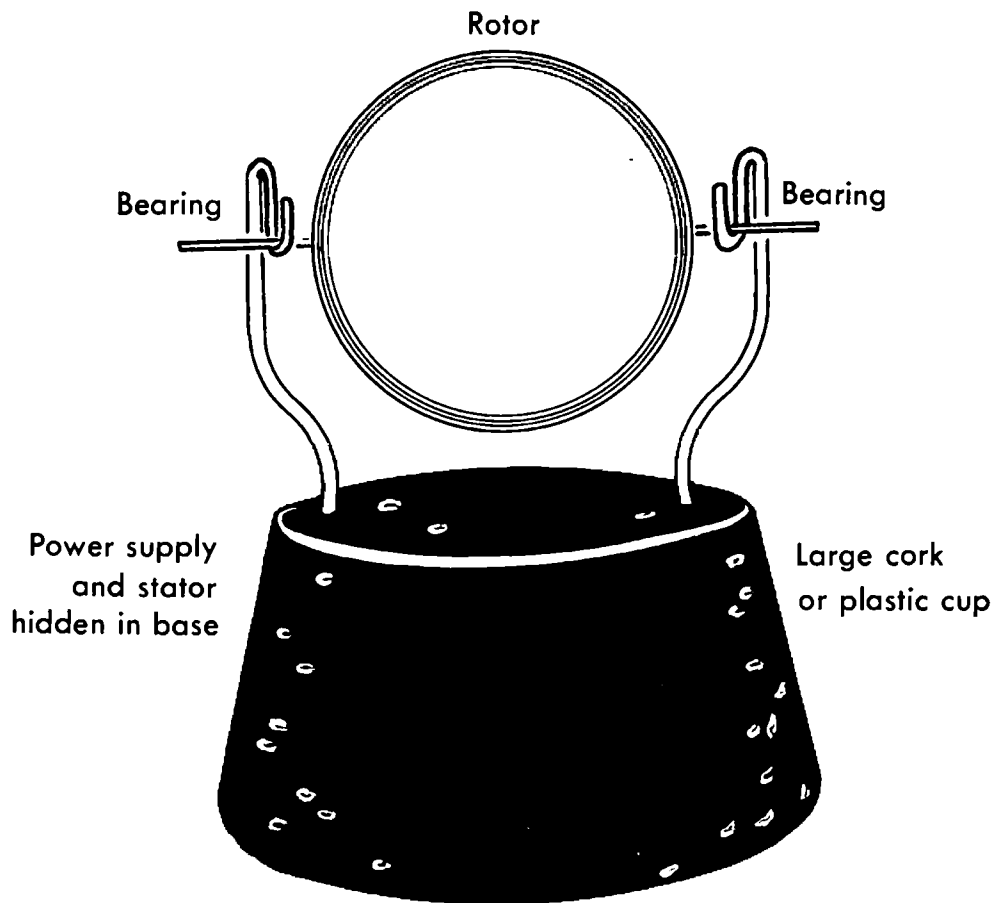
Change the Power Supply

One-and-one-half-volt flashlight dry cells come in many sizes. The larger ones will last much longer. Six-volt lantern batteries are stronger and have a much greater supply of electricity. Nine-volt transistor radio batteries have a still higher voltage or electrical pressure. But they hold only a small supply of electricity. All the cells and batteries can be hooked up in series to supply a more powerful current to the motors. Always hook the connecting wires from positive to negative to positive to negative to positive to negative.



Cells and batteries come in many shapes and sizes

Change the Power Supply



This one will mystify your friends

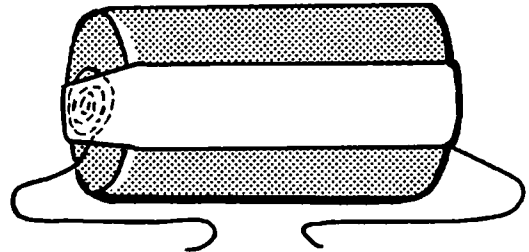
If you hid your power supply and your stator magnet inside a large cork or cut-down plastic foam cup, you could mystify your friends with your Mini Motor.

Change the Cell Connections

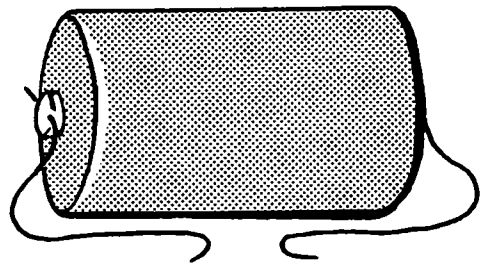
You will be able to do much more experimenting if your power supply is dependable and if you can change it fast.

If you must work with rubber bands to hold your lead wires from the bearings on the dry cell terminals, it helps to make flat, spiral coils on the ends of the wires. Add paper wadding under the rubber band to put more pressure on the wire.

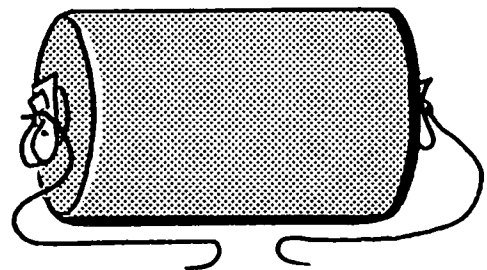
Soldering can ensure very secure, dependable connections. Spring clips such as Fahnestock clips on cells and alligator clips on lead wires can speed your experimenting tremendously.



Rubber bands will work

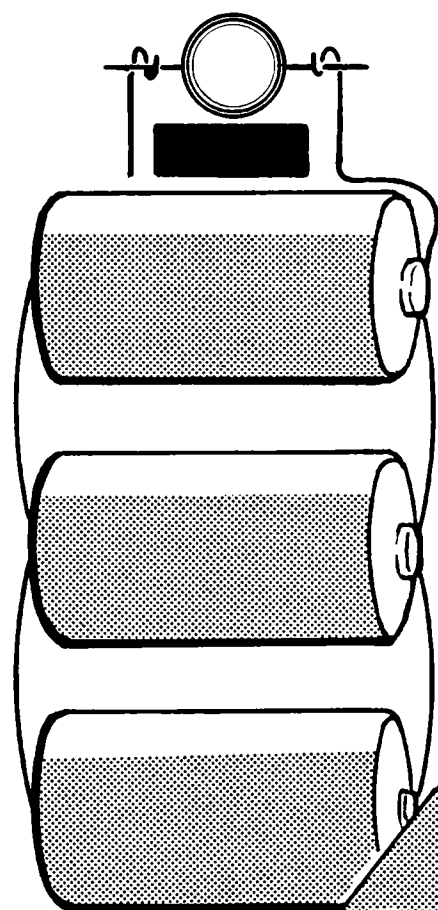


Solder is more secure



Clips make faster changes

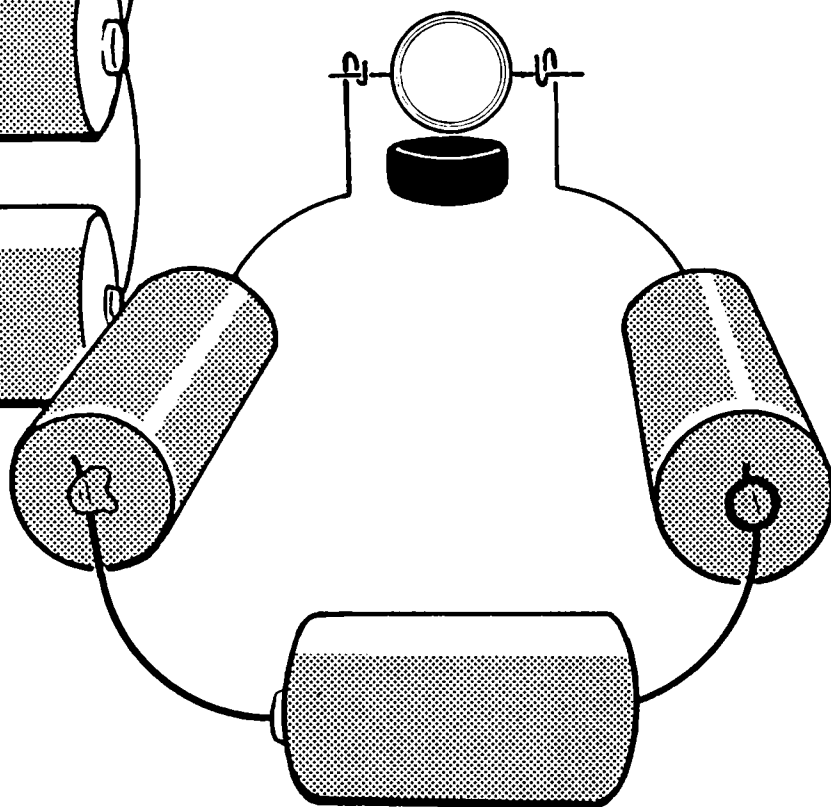
Change the Cell Connections



Parallel circuit

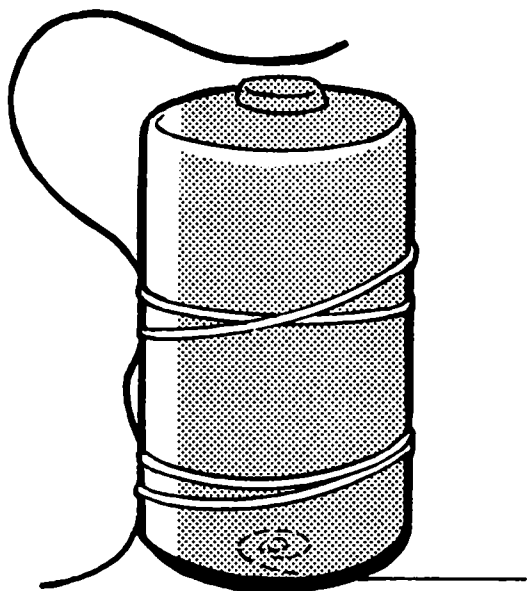
The parallel circuit shown on the left with the cells hooked together looks a little like railroad tracks. Parallel circuits supply power for a longer time.

The series circuit below will multiply the voltage or electrical pressure. Notice that the hookup wires always connect opposite terminals of the cells.



Series circuit

Protect Your Cells with a Switch

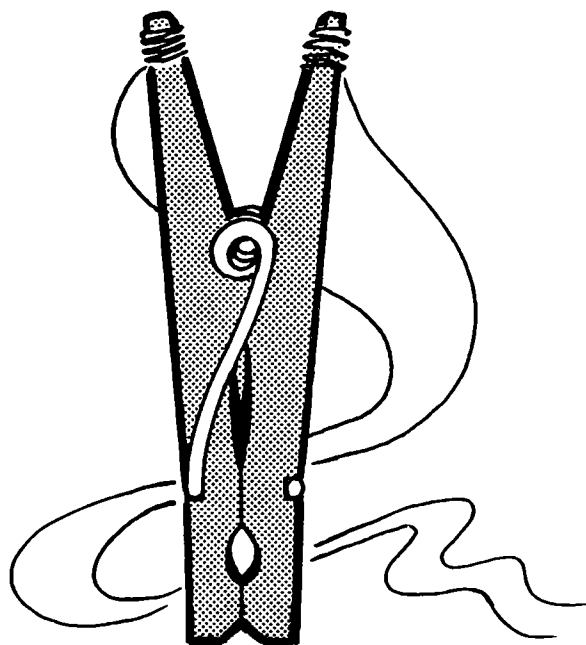


Improvised switch

A switch is merely a break in a circuit. A loose wire, as shown on the left, is a good improvised switch.

Flashlight cells are made for flashing or switching on and off. They are not made for continuous use. Give them time to rest, and they will work much longer for you.

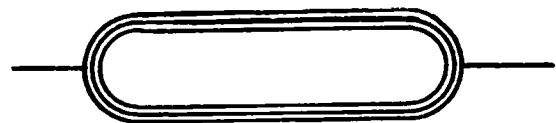
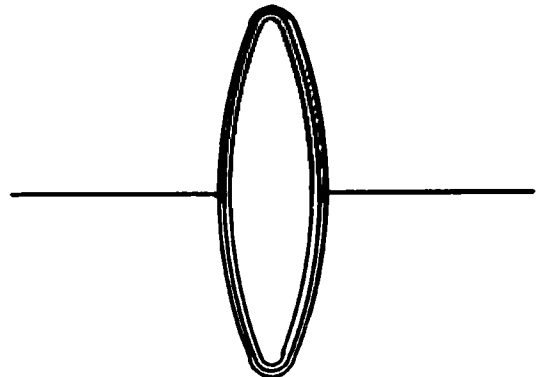
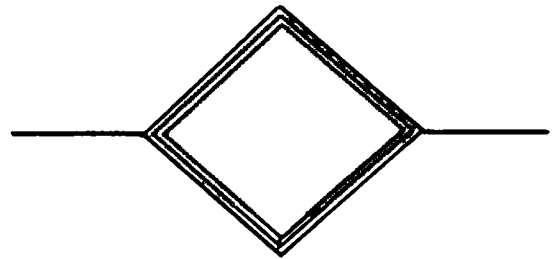
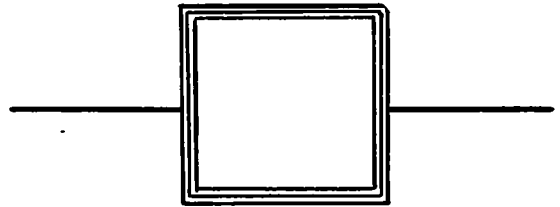
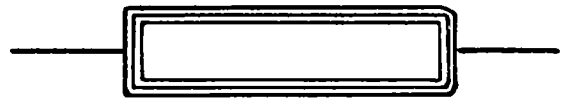
An ordinary clothespin can be made into an ideal switch for use with electric motors. The handles will automatically pop open, turning off the electricity, when you take your hand off the circuit. Cutting notches or drilling holes in the ends of the handles helps hold the wires.



Clothespin switch

Change the Shape of the Rotor Coil

Does shape make a difference? Which shape puts more of the magnetic field nearer the permanent stator or field magnet? Change only the shape. Use the same kind of wire and the same length of wire. Wind the same number of turns on each shape for control. By keeping all the variables under control, except the one you are purposely changing, you will know if any one of the shapes really makes a difference in the motor's performance.

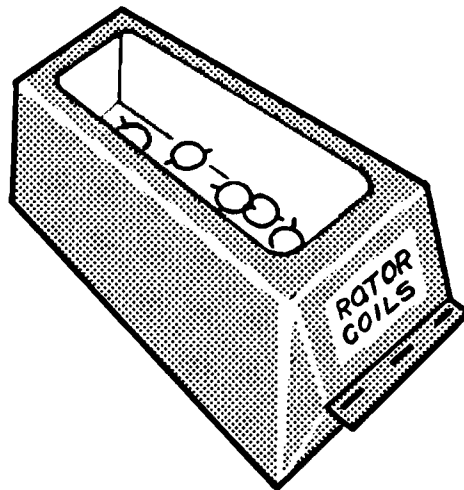


What new shapes can you design?

Start a Filing System for Motor Parts

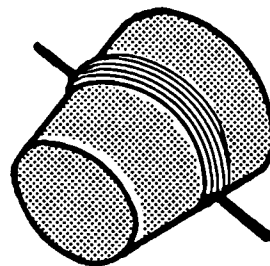
Start a filing system for coils and other motor parts. When you tape your coils, write the number of turns on each. You will be able to use your coils over and over again for experimenting with each new type of electric motor.

Milk cartons make inexpensive filing boxes. Cut an opening in one side with a razor blade or sharp knife. Be sure to leave a half-inch border around the opening. This makes the box much stronger, and it provides a surface so that the boxes can slide over each other. This eliminates the need for shelves when the milk carton filing boxes are organized and placed in a cardboard box such as an apple box. Cover the labels with masking tape and mark them with a felt pen so that you can identify each box. Close the opened end of the gable with flat-pounded copper wire staples, which you can make yourself.



Milk carton filing box

Change the Number of Turns in the Coil

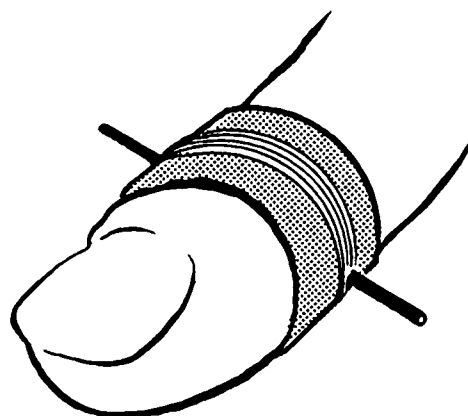


Cork coil form

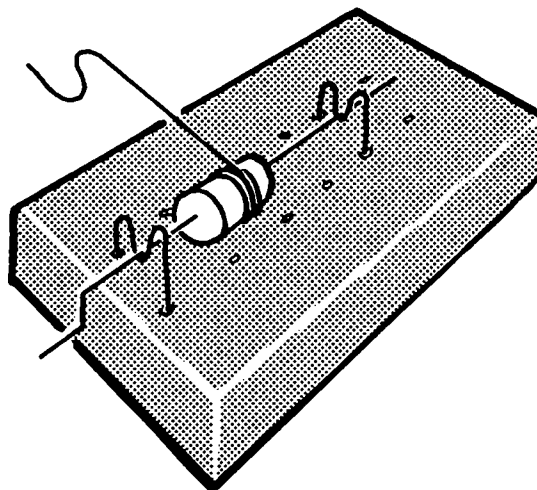
This really means changing the length of the wire in the stator coil. Is one, ten, twenty-five, fifty, or one hundred turns best?

A cork is a good coil form. Stiff paper wrapped around your finger also serves well.

An easy-to-make coil winder is set up by sticking two bent coat hanger wire bearings into nail holes in a block of wood. Masking tape wound around the coat hanger wire can be made into a coil form of any size. A cork glued to the winder has the advantage of its taper. This model is popular because the bearings can be changed rapidly for different sizes and kinds of coils.



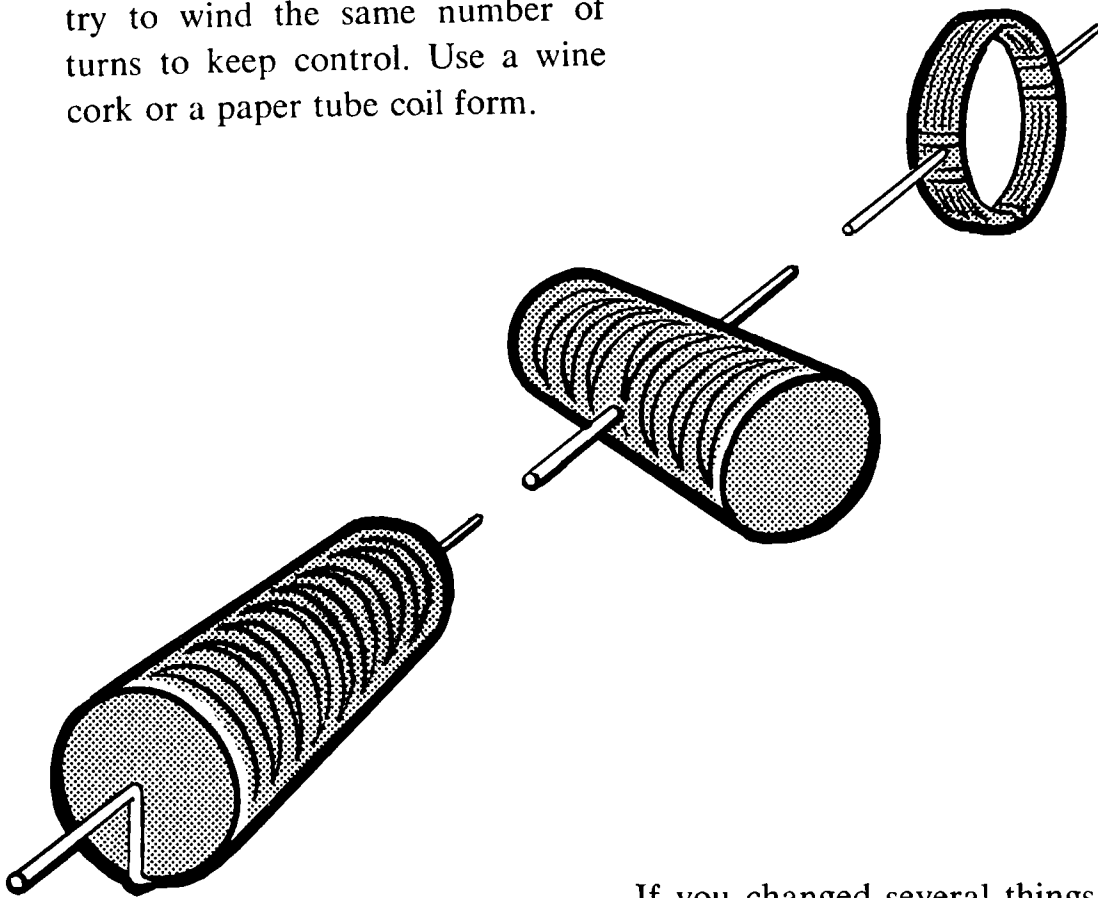
Finger coil form



Coil winder

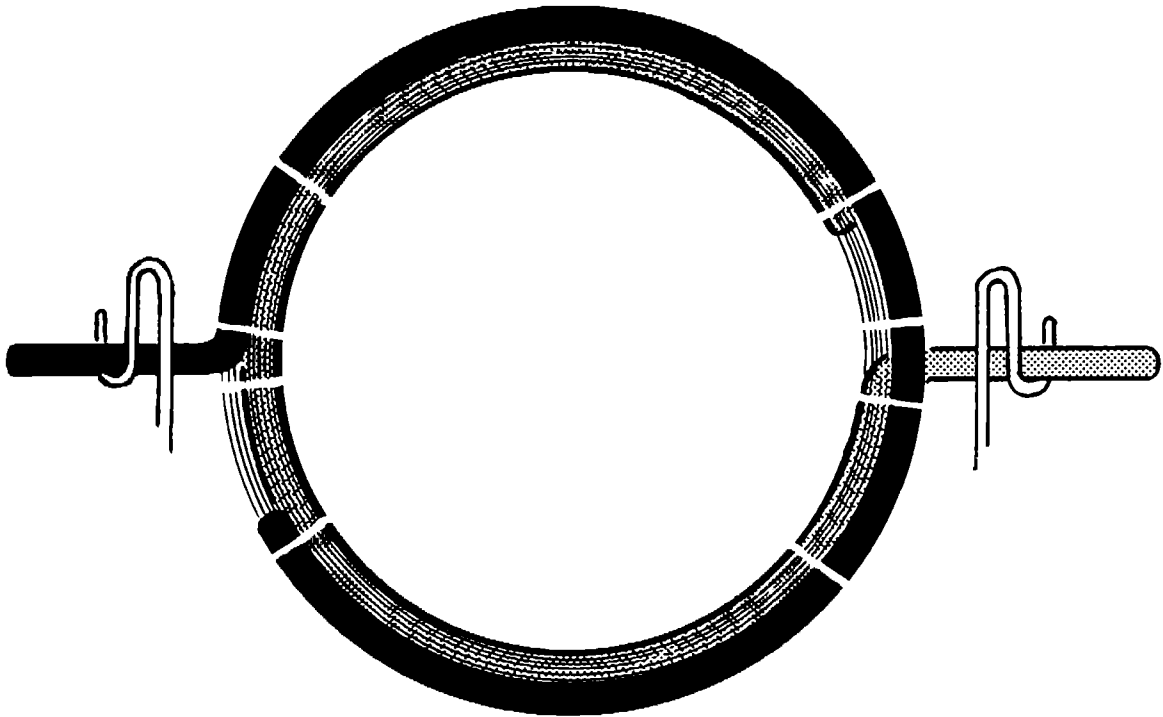
Change the Attitude of the Coil

Use the same length of wire and try to wind the same number of turns to keep control. Use a wine cork or a paper tube coil form.



If you changed several things at once, how would you be able to tell what made the difference in performance?

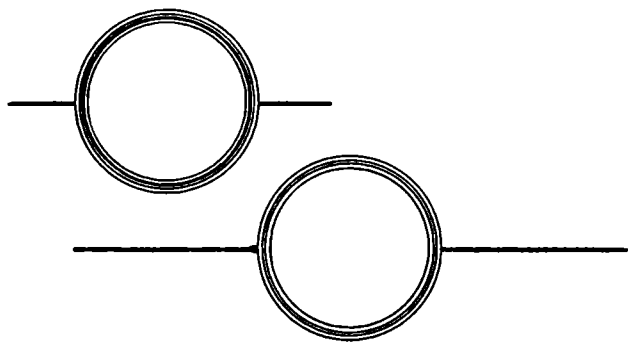
Change the Axle



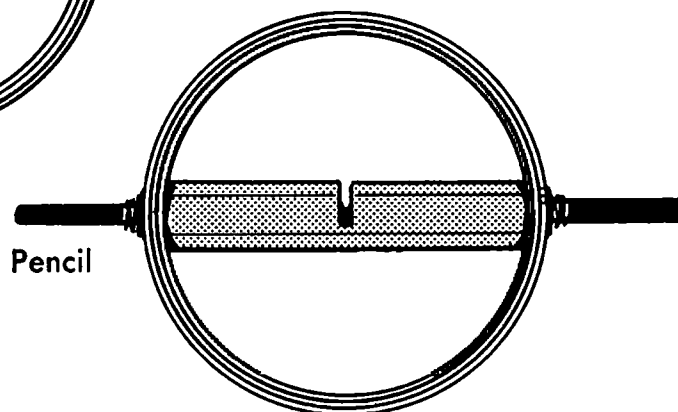
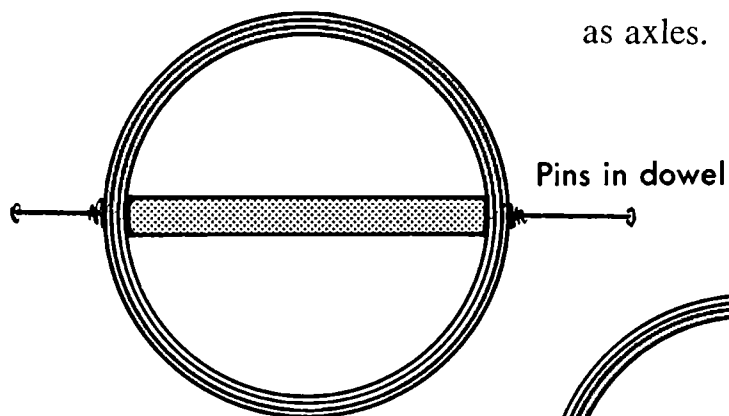
Add stronger wire for axles

You will want to produce more magnetism by adding more and more turns to your rotor coil. When you want to add many turns of thin wire, you will find it desirable to add one loop of heavy wire to each end of the rotor coil for support. Soldering, of course, is the most secure way of fastening the two sizes of wire together. However, they can be made to work if merely twisted together and then tied with thread or tape.

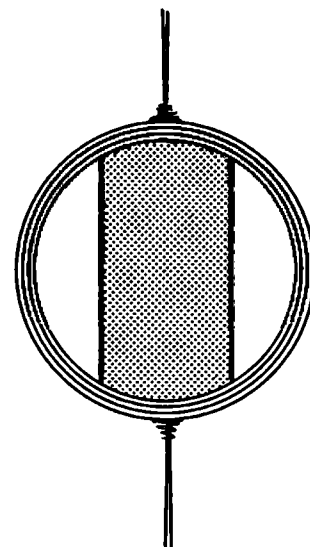
Change the Axle



What is the difference in performance between a long and a short axle? Pins and small nails must be bright and shiny when used as axles.



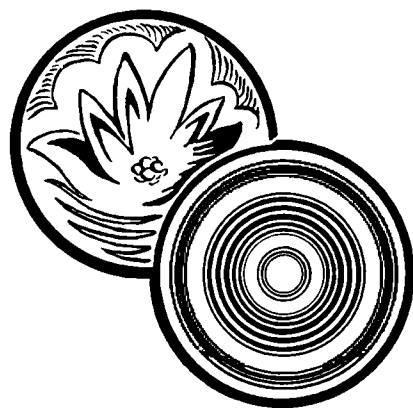
Pencil lead is really graphite, a natural lubricant, which is used on racing cars. The notch must be cut or sawed through the lead to avoid a short circuit. Why couldn't your axle stand on end?



Change the Axle

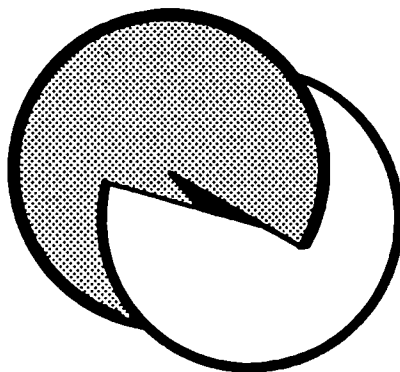
If I pinned colorful disks cut from magazine color pictures to the end of the axle. . . .

You can double the end of the axle to hold the disks more securely.



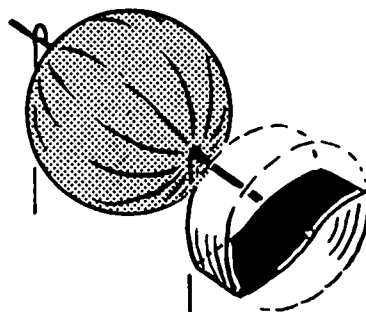
Spin color pictures

If I mixed color disks by slitting them to the center and overlapping them on the end of the axle. . . .



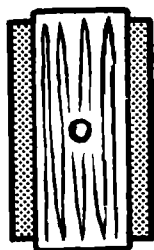
Spin color disks

If I stuck masking tape propellers to the end of the axle. . . .

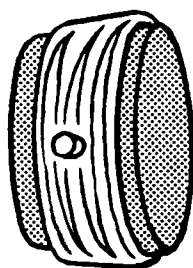


Spin propellers

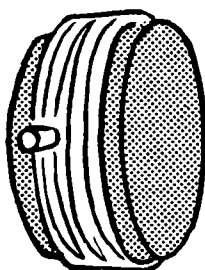
Change the Weight of the Rotor



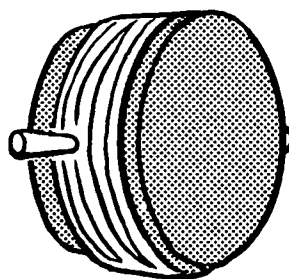
Air core



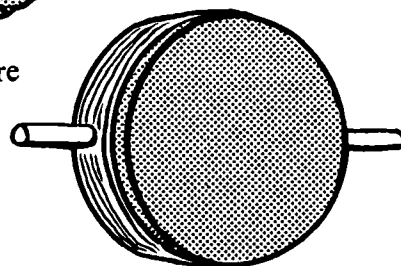
Cork or foam core



Wood core



Metal core



Clay or plaster core

Use the same gauge of wire and the same length of wire for each of the coils. Cut the cores from the same-size cylinders of each material. Keep control.

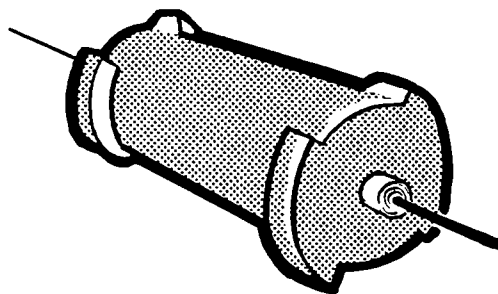
The metal cores should be non-magnetic. They should not be made of iron or steel. Why? Does weight make a difference? What other changes in weight can you design?

Change the Weight of the Rotor

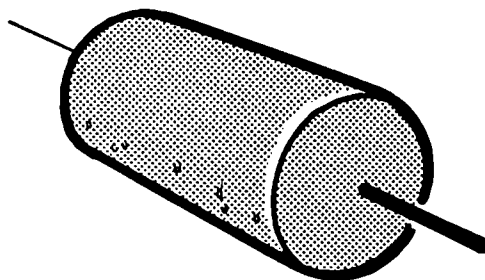
Compare wine cork rotors with wooden spools of the same diameters. Plug the holes in the spool with cork or wooden dowels. Use pins or needles for axles. These axles, of course, must not touch in the center of the rotor. The ends of the coil will be wound around each axle. The rims of the spools can be cut to hold the rotor coil better.

Plastic spools can be filled with many different kinds of materials with varying densities to change the weight of the rotor.

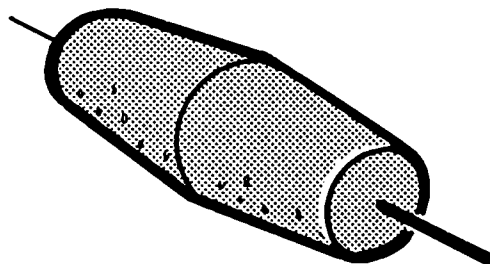
Corks and rubber stoppers can be glued together in pairs to be compared. They can also be compared with the wooden core rotors.



Wooden spool core

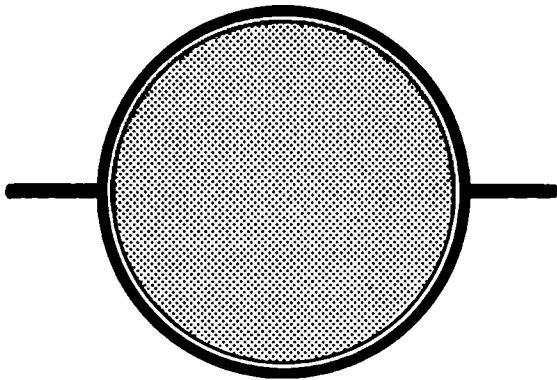


Wine cork core



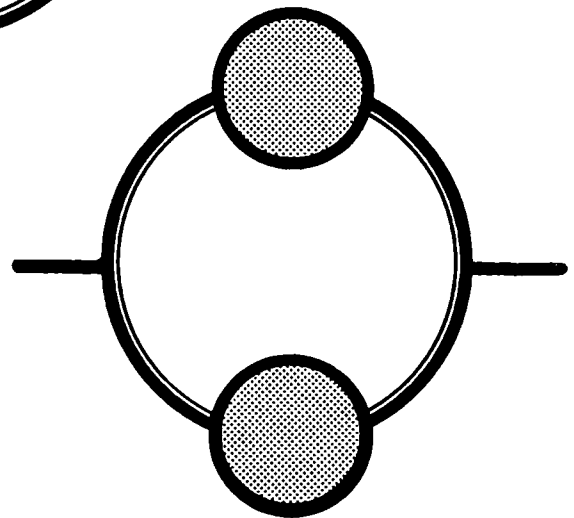
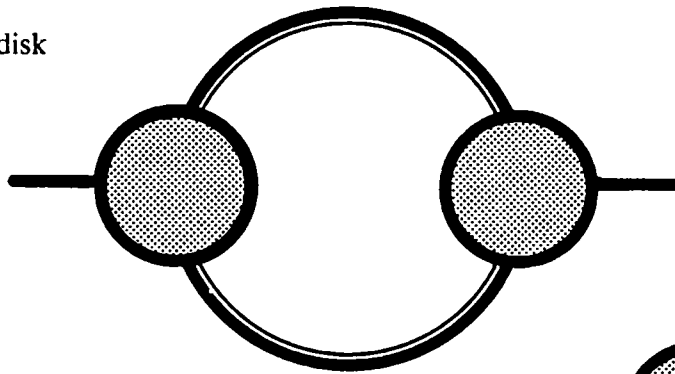
Tapered cork core

Change the Position of the Weight on the Rotor



Clay disk

Wind the coil on a clay disk. Next, cut the clay in half and fasten it to the axles. Last, fasten the clay weights to the far sides of the coil.



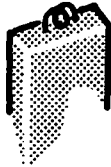
Clay balls (same clay)

Could you use a heavy copper wire for weight instead of the clay?

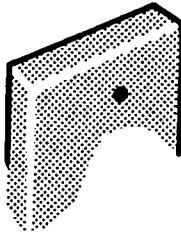
Change the Bearings



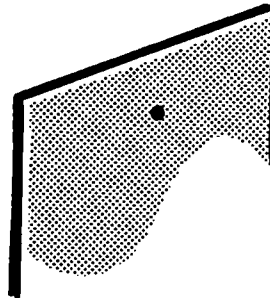
Wire



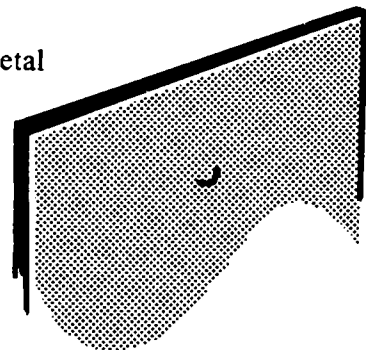
Wire on wood



Hole in wood



Hole in metal

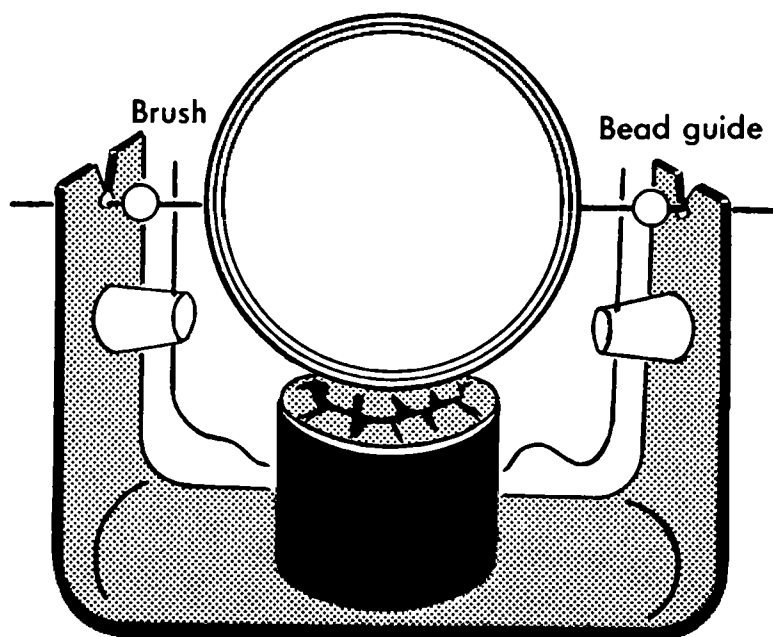


Dimple in metal

Bend the wire differently. It doesn't have to be a cradle bearing. You can bend wires into holes on wooden posts and metal supports. Dimples can be used on metal supports and wooden posts.

A straightened Fahnestock clip makes a handy bearing. The most important point about the bearings on experimental motors is that you should be able to change the rotor fast.

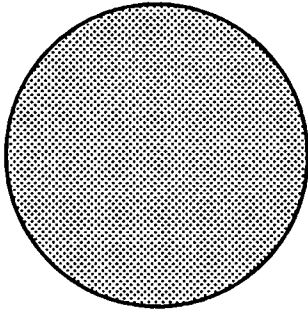
Change the Bearings



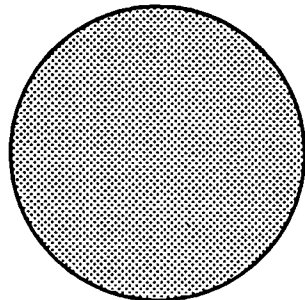
Plastic bottle base-and-bearing combination

Cut the bottom off a plastic bottle with tin snips or a razor blade. Use it for a combination of base and bearings. The most often used polyethylene plastic is a waxy, self-lubricating material. Drill the bearing holes with a hot needle or a hot nail. Cut a V down to the holes with a razor blade to make them into cradle bearings for quick rotor changes. You must hold the circuit wires with two corks so that they brush against the axle because the polyethylene plastic does not conduct electricity. Glue and pin the corks to the flat bearing posts. Insert the circuit wires from the dry cell through needle holes put through the corks. Bend these wires so that they brush lightly against the axle.

Change the Strength of the Stator Magnet



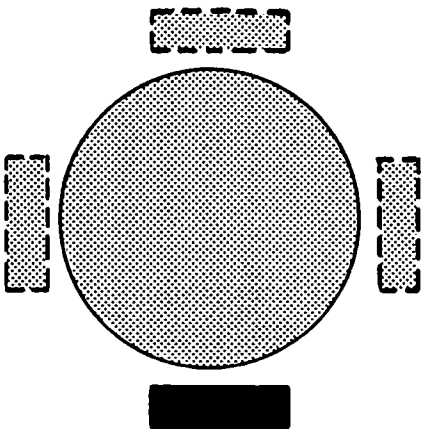
If I switched the positions of the poles by turning over the stator magnet. . . .



If I moved the stator to each of the three positions on the base as suggested at the left. . . .



If I put the stator in each of the four positions around the rotor. . . .



If I used four stator magnets instead of just one. . . .

Change the Position of the Stator Magnet

You are probably using ten little Alnico bar magnets secured together as your stator or field magnet because these were suggested to you at the beginning of this book. Have you tried to run your Mini Motor with just one bar magnet as a stator? Are ten magnets that have been bound together ten times as strong as a single magnet stator? How could you find out? Have you tried other magnets of differing strengths yet? Have you tried other kinds of magnets such as ceramic rounds and flat rubber magnets as stators?

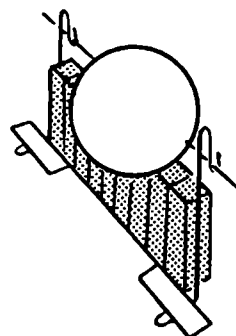


Try other kinds of magnets

Change the Shape of the Stator Magnet

If I stood the stator magnets on end and parallel with the axle. . . .

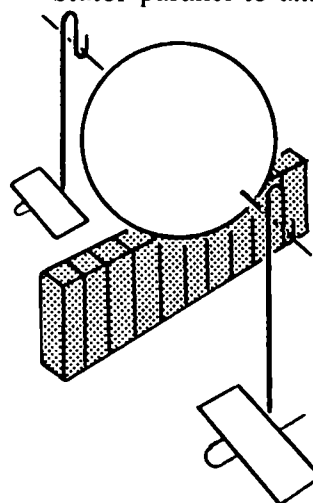
Fasten the magnets in line with masking tape. Prop them upright with tape or with clay.



Stator parallel to axle

If I stood the stator magnets on end and at right angles to the axle. . . .

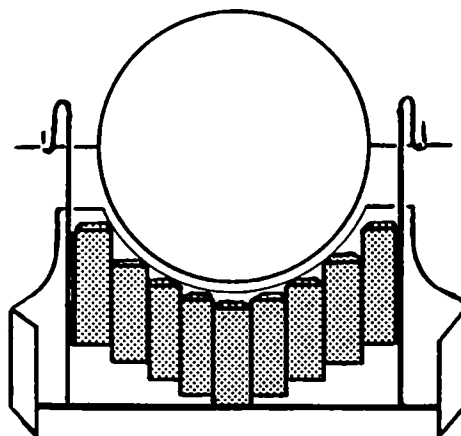
Also try doubling the magnets in pairs on both sides of the tape so that the force is more concentrated.



Stator at right angle to axle

If I contoured the bar magnets in line around the rotor. . . .

Glue the magnets to a note card or to cardboard.



Stator contoured to rotor

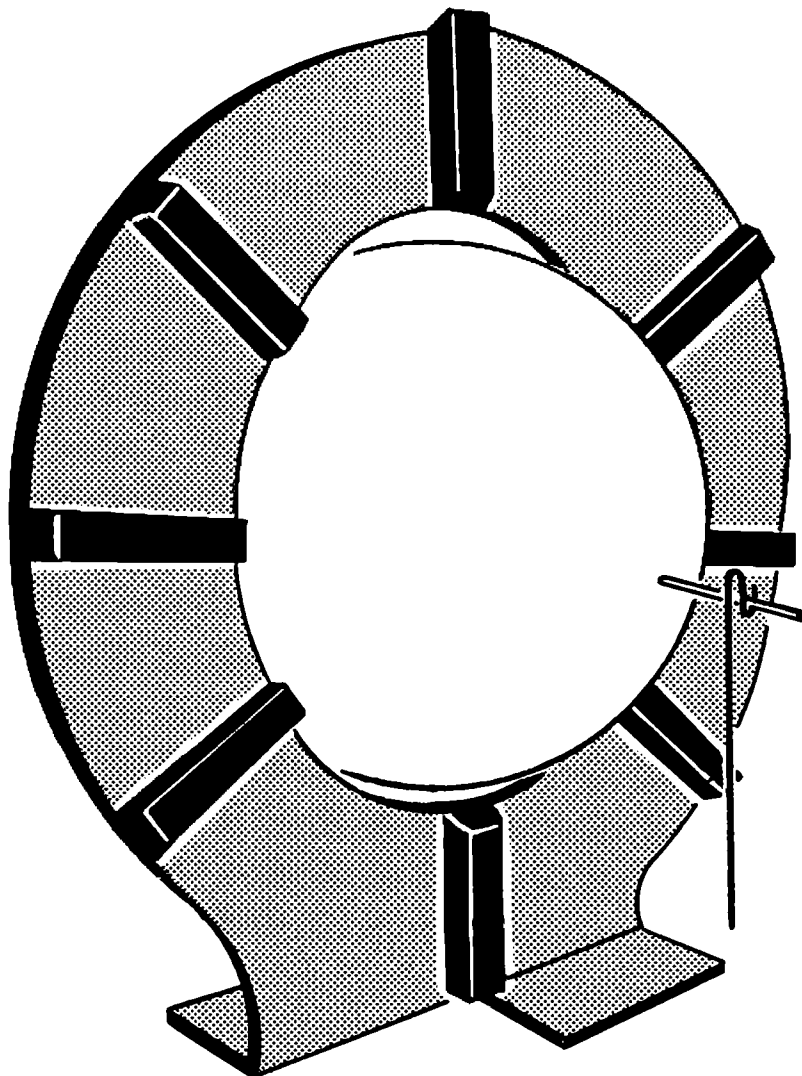
If I used a flat rubber magnet and wrapped it in a circle around the rotor. . . .

Change the Shape of the Stator Magnet

If I glued the magnets in a circle around the rotor on a circular piece of cardboard. . . .

If I doubled the magnets in a circle by placing them on both sides of the cardboard circle. . . .

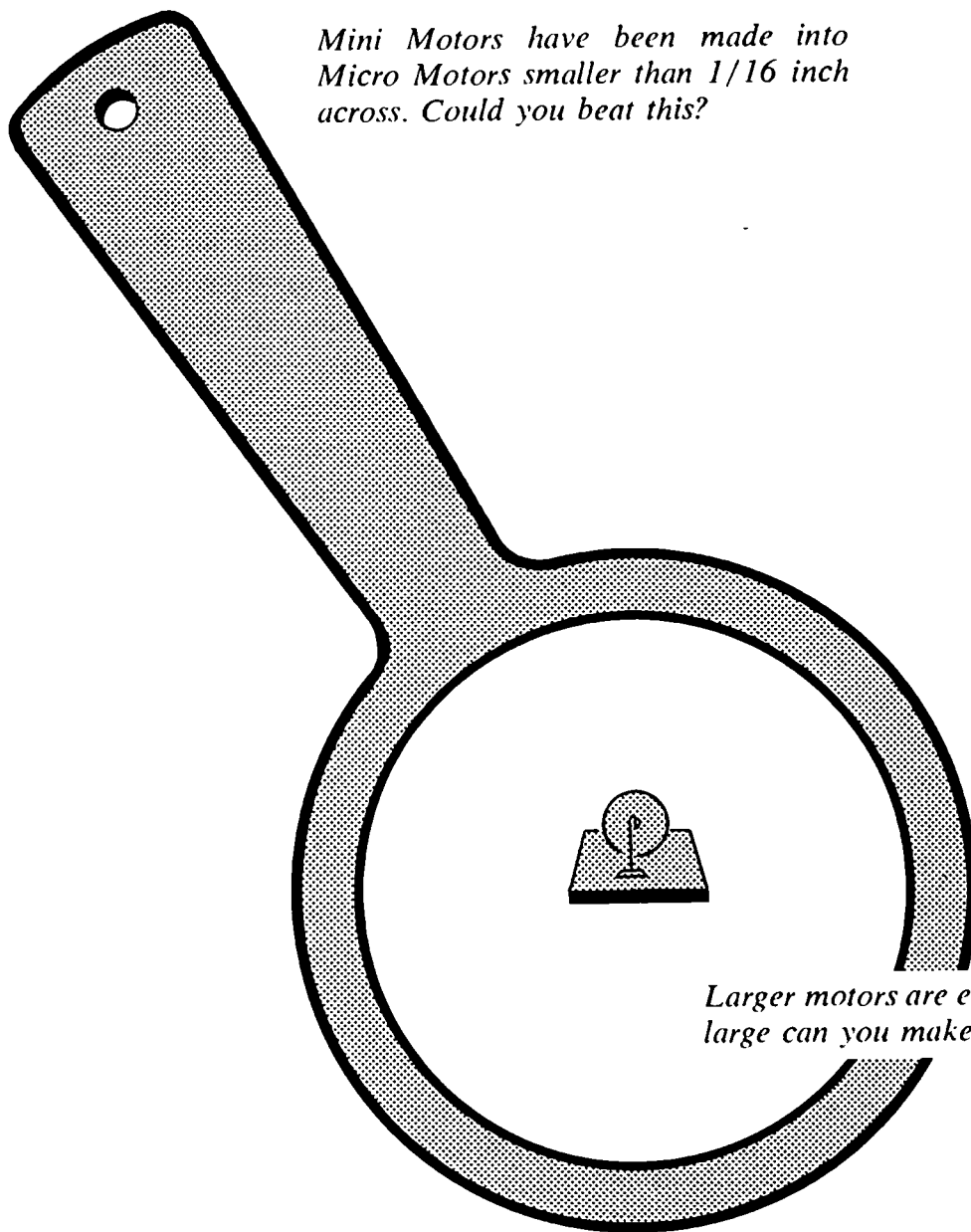
If I changed the polarity of the multiple magnets of this stator built in a circle. . . .



Cardboard support for stator magnets

Change the Size of the Mini Motor

*Mini Motors have been made into
Micro Motors smaller than 1/16 inch
across. Could you beat this?*

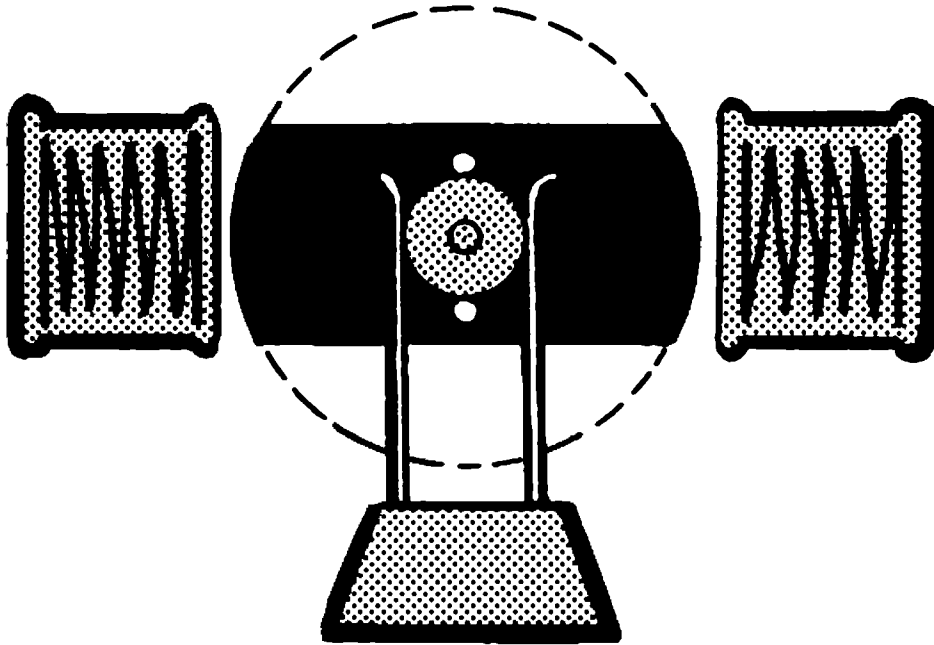


*Larger motors are easier to make. How
large can you make the Mini Motor?*

Could you build a motor under a microscope?

3

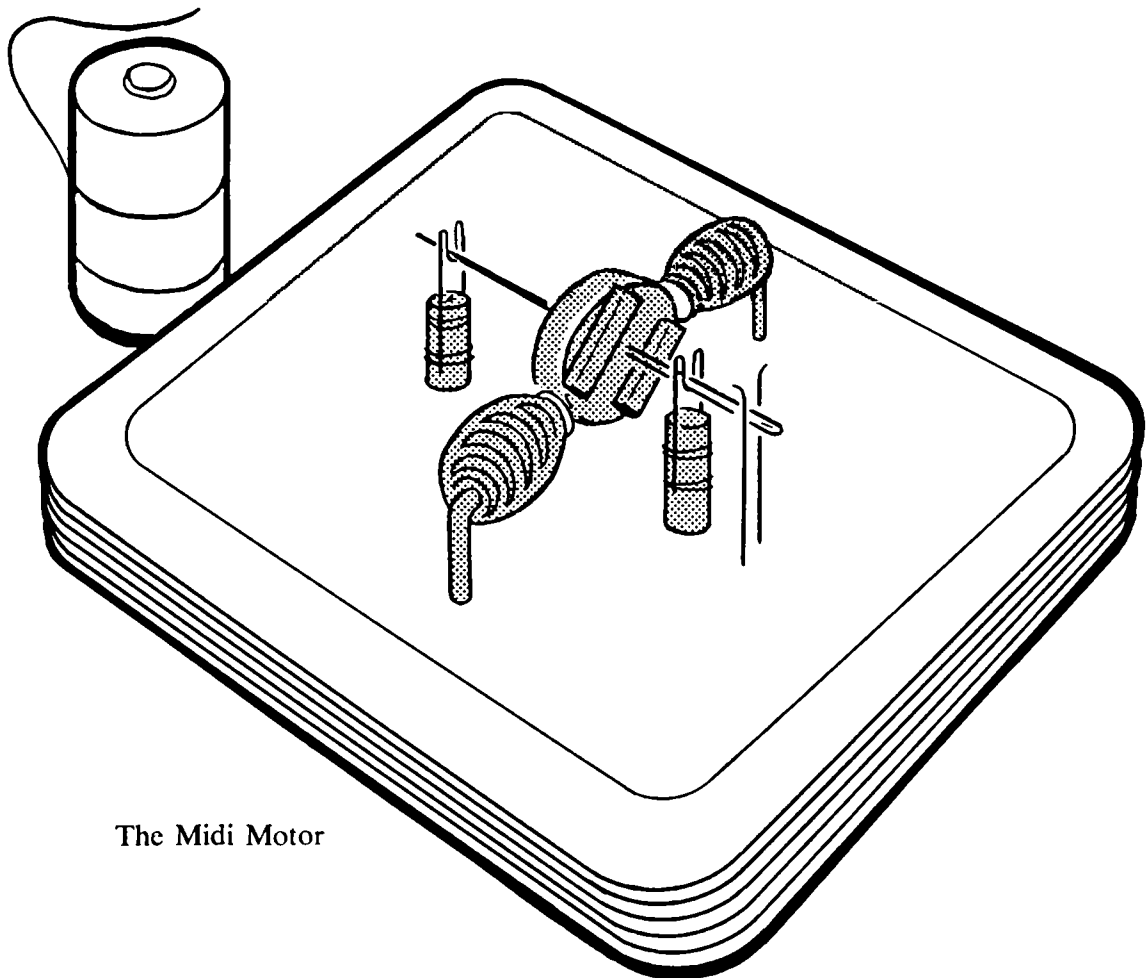
The Midi Motor



The Midi Motor is arranged just opposite to the Mini Motor. It has permanent magnets on the rotor or armature, and it has electromagnets for its stator or field coils.

This Is the Midi Motor

Each step of the assembly will be illustrated on a separate page. The Midi Motor, too, is designed so that you can change the parts easily for experimenting. Because of the foam base, you can make this motor also without tools. But if you can gather a few tools, they can speed your experimenting. You will especially appreciate the use of some masking tape and some clip leads as you experiment with the Midi Motor.



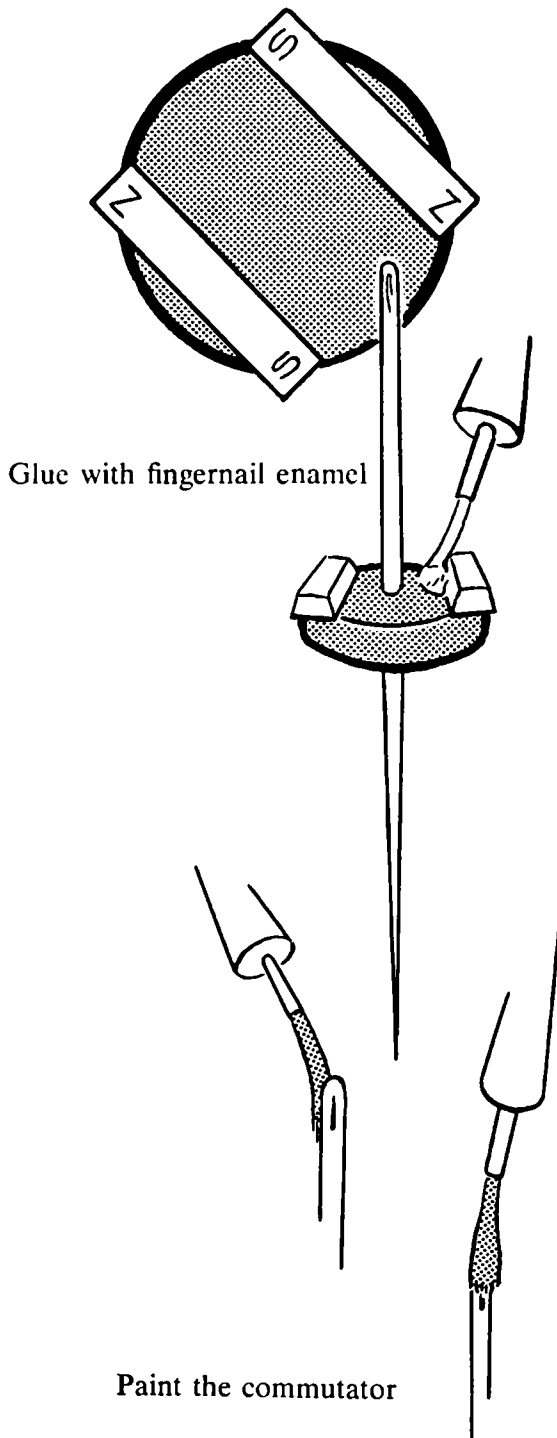
The Midi Motor

Glue the Magnets to the Rotor First

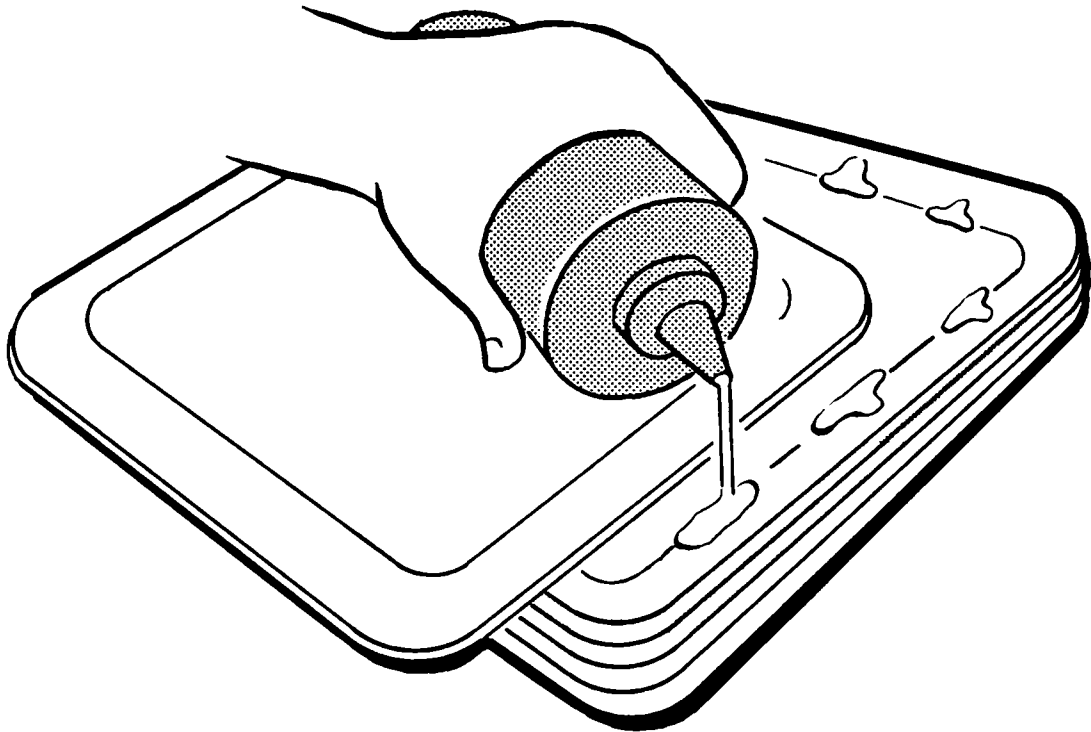
The best axles are made from four-to-six-inch-long upholstery needles. Buy them at upholstery stores. Stick the axle through the center of the cork disk. Spin the rotor to be sure that you have centered it well.

Glue the magnets to the cork with fingernail enamel. Be sure that the opposite poles face each other and that all poles are the same distance apart in all directions.

Stand the needle in a foam tray, and paint both sides of the eye with the fingernail enamel. The thin edge around the eye should not be painted. This painted end of the needle will be the commutator, which is the spinning switch that turns the stator magnets on and off at the right time.



Make a Plastic Foam Base



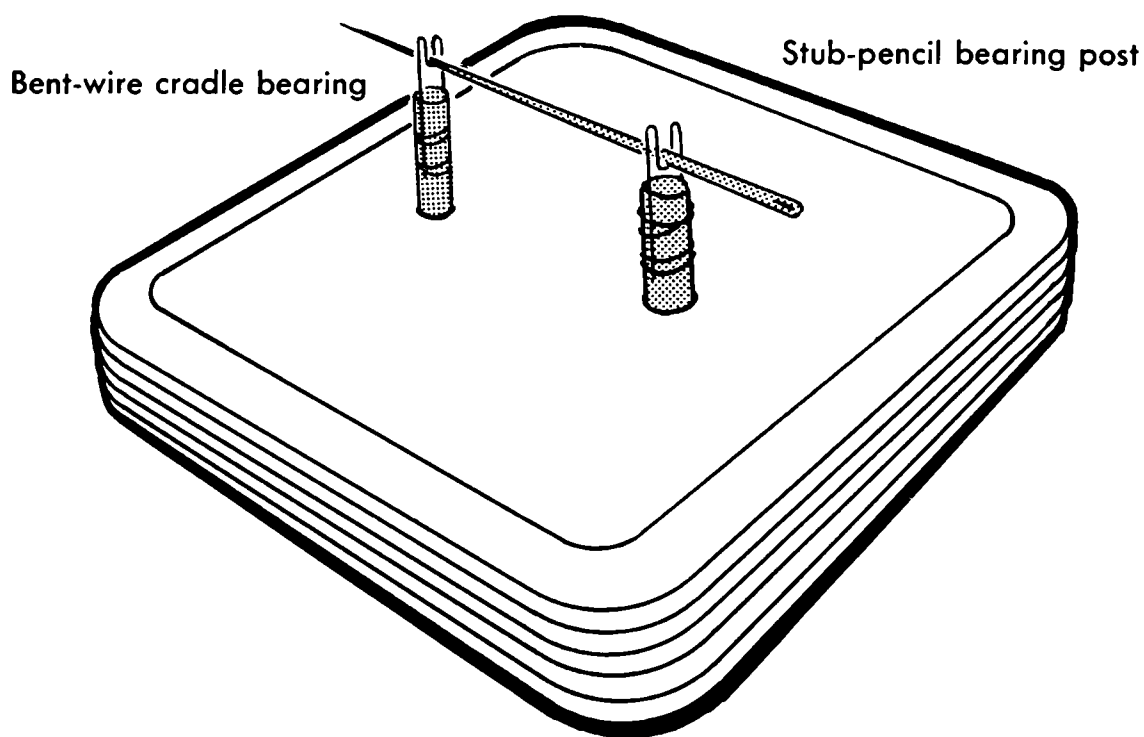
Pin and glue foam meat trays together

Pin four or five urethane-foam meat trays together for a base on which to build this motor. Fasten them with a water-soluble glue. Add a weight and leave them until the glue is dry. The meat trays can be purchased for pennies from your local butcher. Foam blocks and sheets can be obtained from many stores where they are used for packing. The foam is exceptionally easy to cut and to shape with a knife, a razor blade, or a saw. Plastic foam is ideal for a base because it makes it so easy for you to adjust the bearings and the brushes of your electric motors without tools.

Add the Bearings

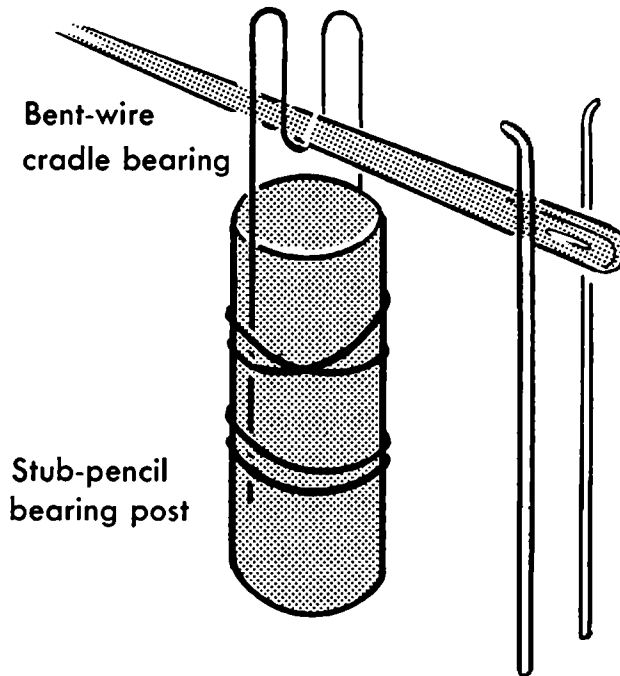
Stub pencils serve well for bearing posts when sharpened because they can be pushed into the foam base easily. They then can be adjusted up or down to ensure the best placement of the stator magnets. Wooden dowels, sticks, and even twigs can be used as bearing posts when sharpened.

The bearing cradle wire should be long enough so that both ends will extend at least halfway down the bearing post. You will want to change the height of the rotor as you experiment. Shape the cradle of the bearing wire around a pencil point. You can find a part of this tapered point that will fit any axle. Then bind this bearing wire to the bearing post with a small rubber band. Test it to see if you can still adjust the cradle wire up and down. Balance the rotor on the bearings.



Twist stub-pencil bearing posts into the foam base

Put the Brushes in Place



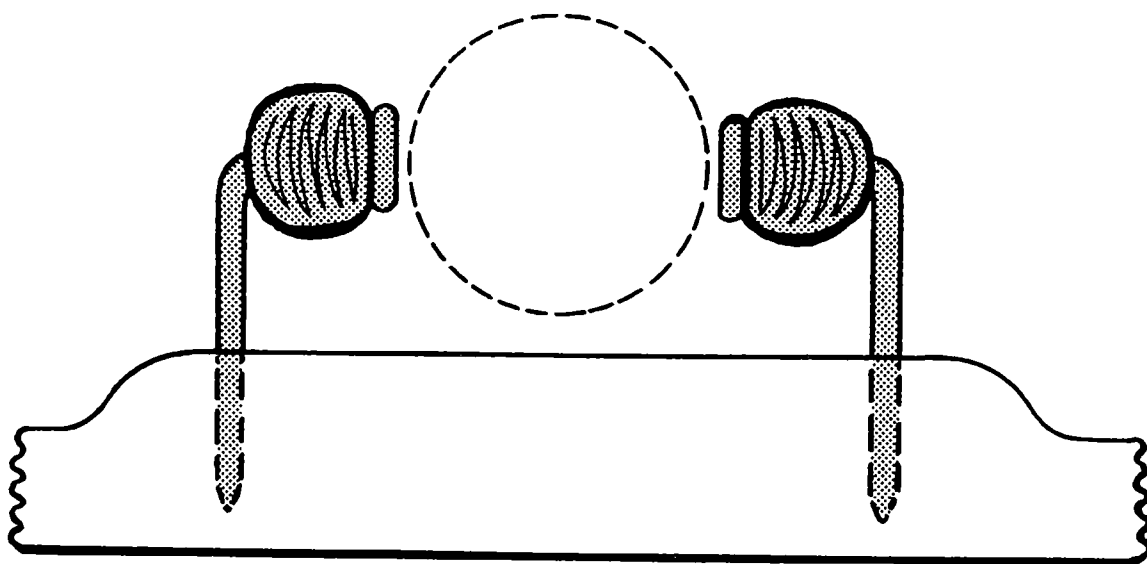
Make copper wire brushes

The brushes for the Midi Motor are two straight, bare copper wires that contact the spinning-switch commutator, which will turn the stator magnets on and off at the right time. Use a small needle to stick two holes through the plastic foam where you want the two brushes to stand under the commutator. The two holes should be about $\frac{1}{8}$ inch apart. One brush will be the end of the lead wire from one of the stator coils. The other brush will be the lead wire from the power supply. Both wires should be threaded upward through the foam base to stand side by side. The standing ends of the brushes must be clean, bare, and bright.

Wind Your Stator Coils

Bend the heads of two 3-inch-long nails at right angles so that the heads will face the spinning rotor. You will need about 8 feet of #18-to-#22-gauge, varnish-insulated magnet wire to wind fifty turns on each of the stator cores for this Midi Motor.

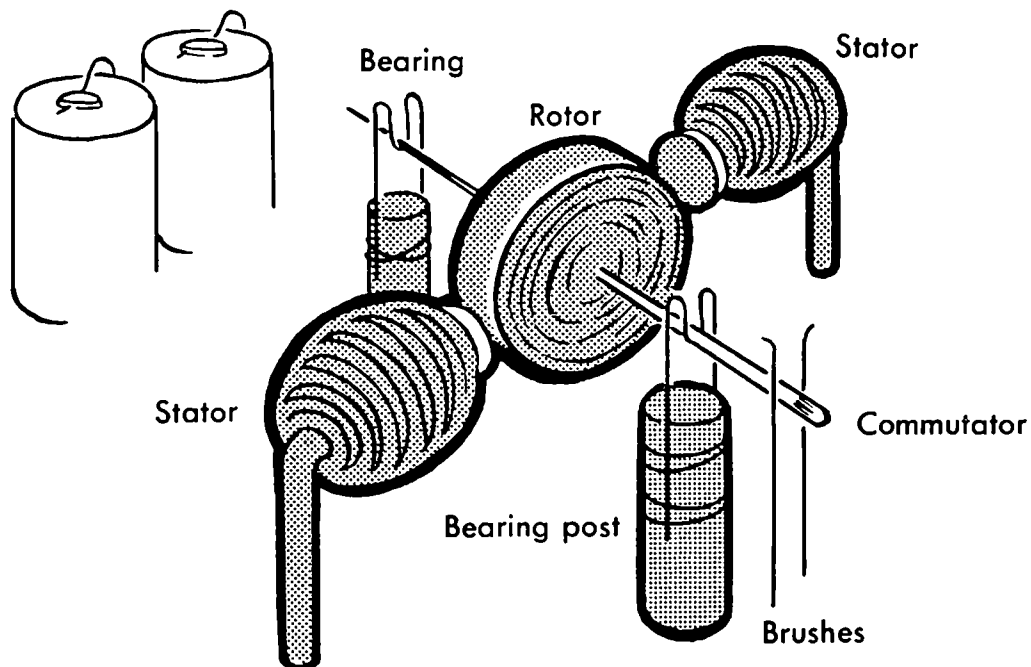
Start with one nail by leaving a 6-inch end of wire free for a lead wire. Then wind fifty turns on the top bent end of the nail. Stick this stator in place on the foam base. Stick the other stator nail in its place on the other side of the base. Bring the wire under the base, and wind fifty turns on the other nail. Be sure to wind both coils in the same direction so that the heads will have the same polarity. Leave a 6-inch end for a lead wire, and cut off the extra wire. Adjust the stator heads to make them level with the axle.



Use bent nails for stator cores

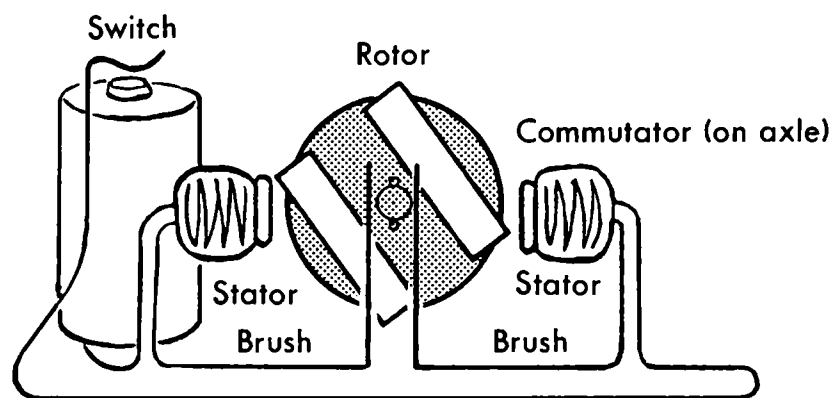
Put the Rotor in Place, Add Power, and Watch It Spin

Slip the rotor or armature into the cradle bearings. It may help to bend a V at the top of the brushes to slip the rotor in and out more easily. Spin the rotor with your fingertips. Check to see that the brushes are rubbing against the commutator part of the axle. Use three volts of power to start your motor and to adjust it. It should run on one and one-half volts after it has been adjusted. When it is running, there should be a shower of tiny sparks each time the axle turns over. If the Midi Motor does not spin by itself, the timing of the commutator must be changed by holding the axle with a pliers and turning the cork rotor slightly.

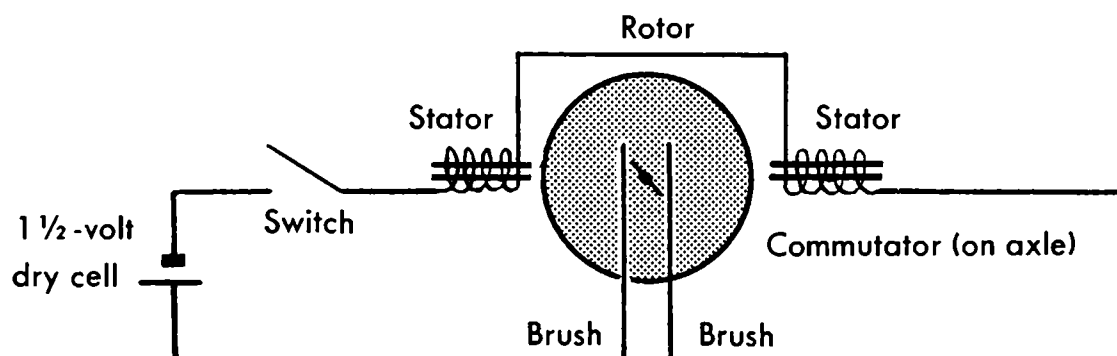


The Midi Motor

This Is the Circuit for Your Midi Motor



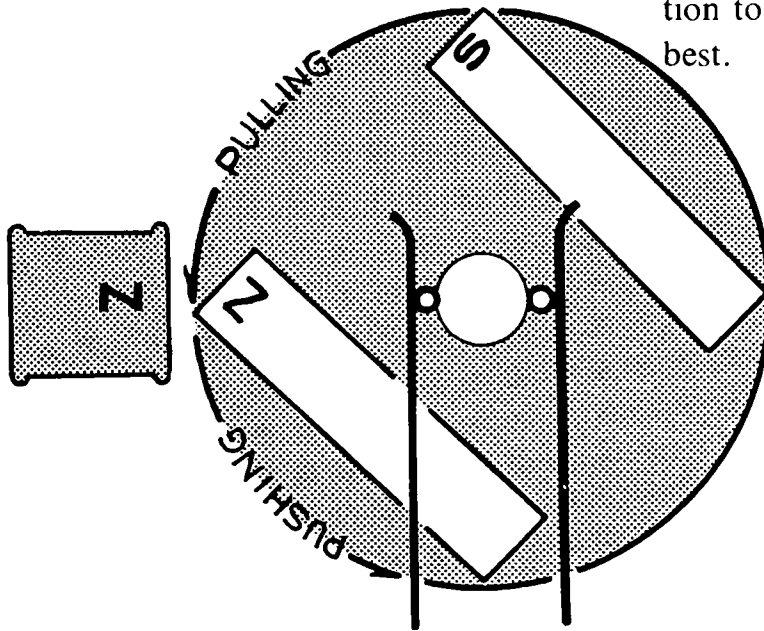
Pictorial drawing of circuit



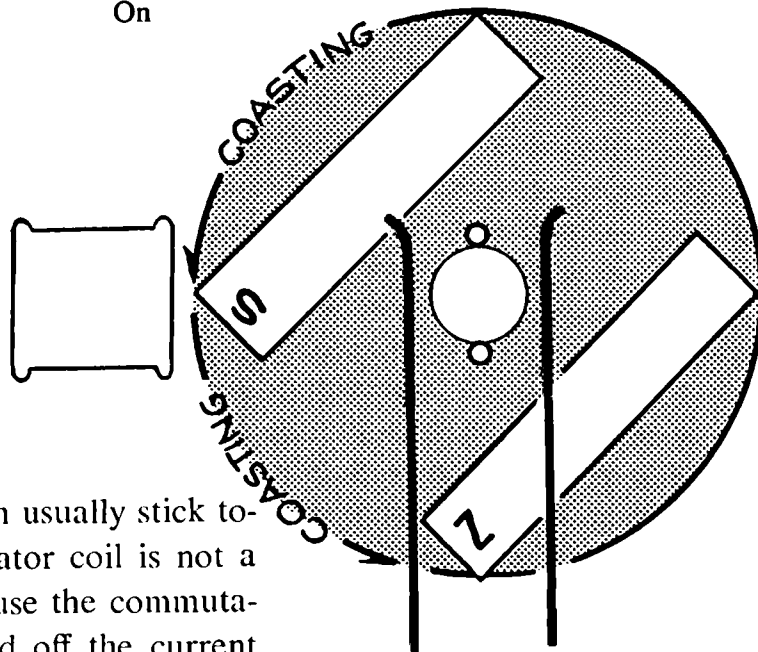
Schematic drawing of circuit

How to Adjust the Commutator

Twist the cork disk of the rotor until the magnets are in the best possible position. When the commutator switches on the current, the magnets should be in this position to repel and attract each other best.



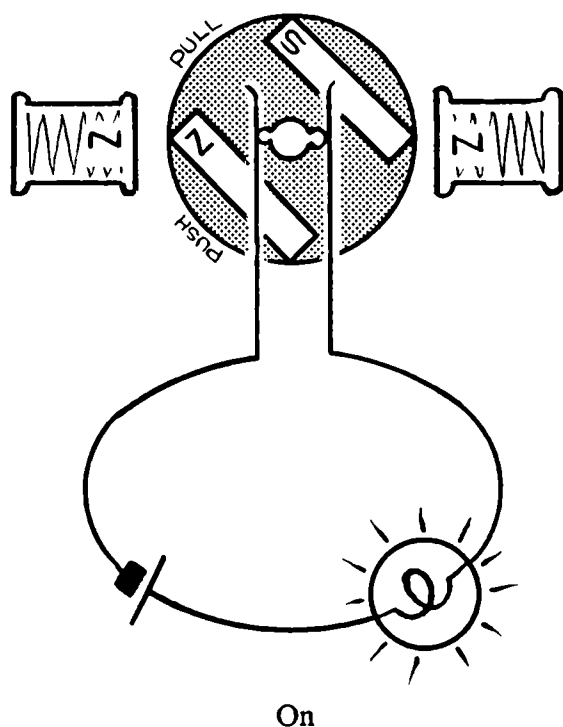
On



Off

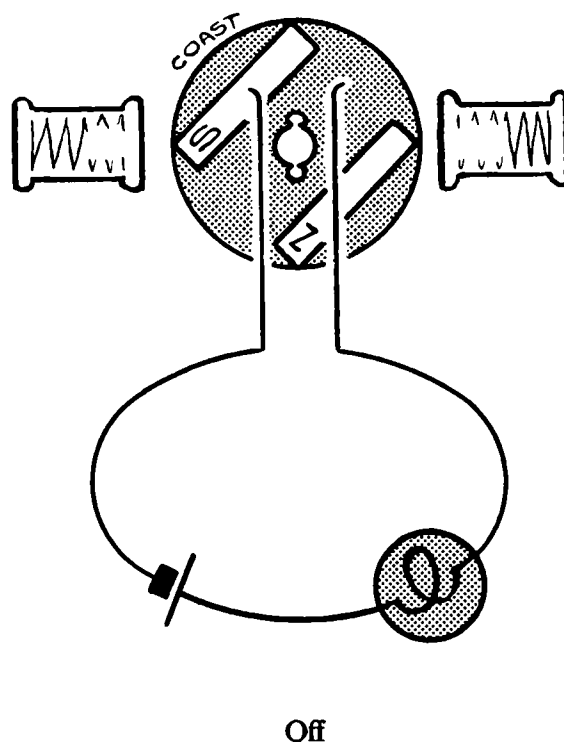
North and south usually stick together. But the stator coil is not a magnet now because the commutator has just turned off the current flow.

Test the Timing with a Light



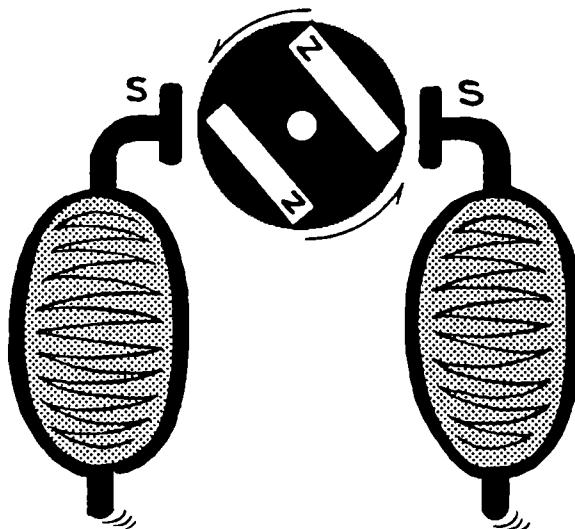
A miniature light bulb in the circuit sometimes can help you see where the invisible electricity is flowing. Do you really have a circuit? This is the first question you should ask when trouble occurs.

If you do have a complete circuit, a light should turn on and off as you turn the rotor slowly with your fingers. Next, check to see if it turns on twice with each revolution. If the light comes on at the correct time, but your motor still will not run, you must next check the polarity of your magnets.



Check the Polarity of Your Magnets

The direction of current flow determines the polarity of an electromagnet. Change the connections to the dry cell to change the poles of the magnetic coil. Or you can rewind the coil in the opposite direction if one of the pair is polarized wrong. Remember that in almost all the Midi Motors which you will be making, you will want the two stator coils polarized in the same direction. The one exception to this arrangement is done when you change the attitude of the permanent magnets on the rotor to be parallel to the axle. The stator magnets also must be placed parallel, and they must be wound in opposite directions so that they will have opposite polarity this one time.



Polarity of Midi Motor stators must be the same

It Is Time to Experiment Again

It is harder to get this Midi Motor started because of the timing. And right away we are going to suggest that you take it apart to change it. This is when your learning really advances.

The changes that you may want to make do not necessarily have to follow the order of those suggested in this book. If you have your own idea for changing some part of the Midi Motor, go ahead right now. You are a much better experimenter when you can design your own changes.

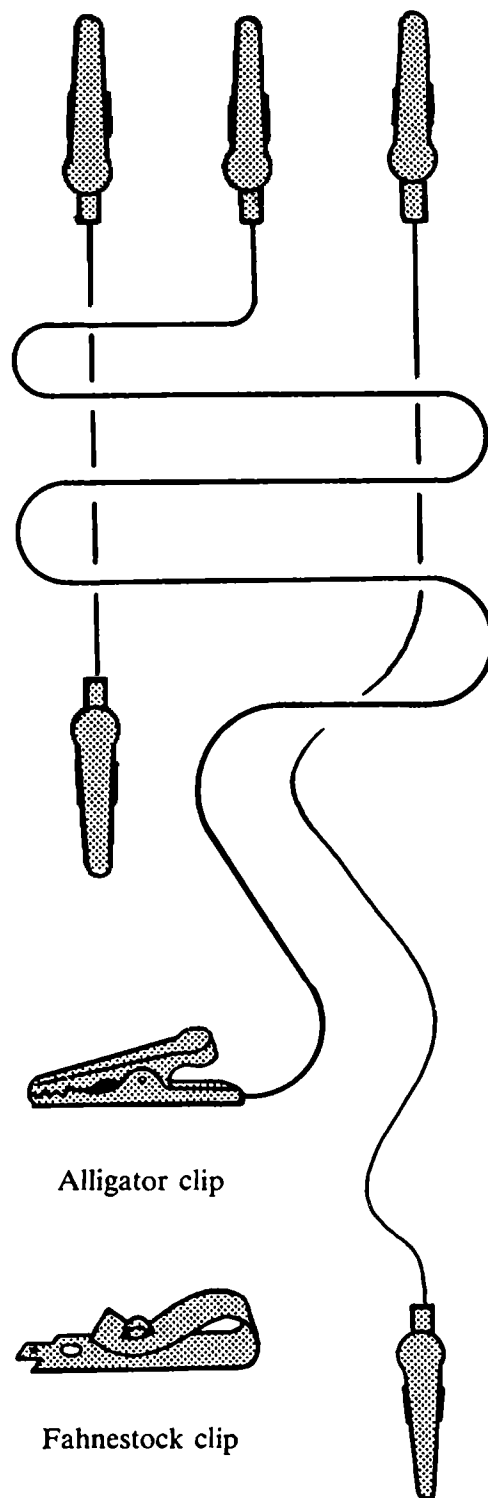
When you make changes, try to go to the extremes first. You will find out faster what variables really make a difference. Should the magnetic poles of the rotor be close to the axle, or far out, or perhaps in between? Try the extremes first. Then you may be able to tell right away how much you may want to explore in between. Should the commutator have a large diameter or a small diameter? Do not change it just one hundredth of an inch. First, test it to the extremes of the size of the equipment which you have available. Is there much difference between the performance of a thin needle axle and a thick nail used for the same purpose? Is thin wire really better for the Midi Motor than thick wire? Is thin varnish insulation better than the thick plastic covering for making an electromagnet? You can find out if you ask your motor specific questions, and you will learn faster by changing to the extremes first.

Clip Leads Will Speed Your Experimenting

Clip leads such as those shown on the right can speed your experimenting tremendously now that you are ready to produce your own magnetism with electricity. Clip leads will help you change connections much faster, and they will make the connections more secure.

You can buy miniature clip leads. Or you can make your own if you have a soldering iron, some solder, some cleaning flux, and some of the smallest-size alligator clips.

Fahnestock spring clips of the smallest size also are convenient for quickly connecting wires. And they are excellent for making permanent terminal connectors. They can be straightened, too, to be used as bearing posts.



Alligator clip

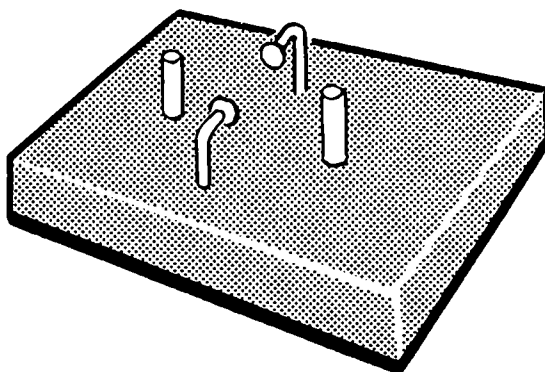
Fahnestock clip

Change the Base

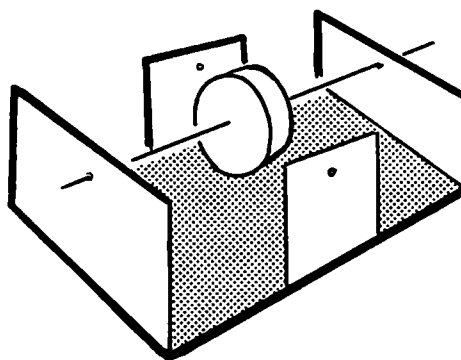
Wooden blocks have been used as bases for many years. They can still be used, but they require that you have a drill to make holes for the bearing posts and brushes.

Metal sheets also have served well, but these are even harder to drill. And they have the added problem of causing short circuits.

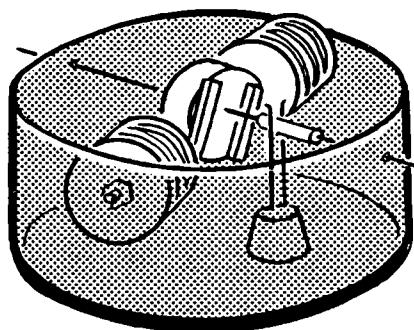
Plastic blocks, trays, and bottles are now being used for motor bases because they are so easy to obtain and because they are so adjustable. Styrofoam blocks and urethane foam trays are easy to cut or saw. Circuit and bearing holes do not require a drill. And, best of all, when you use a plastic bottle, the bearings will already be part of the base.



Wooden block base

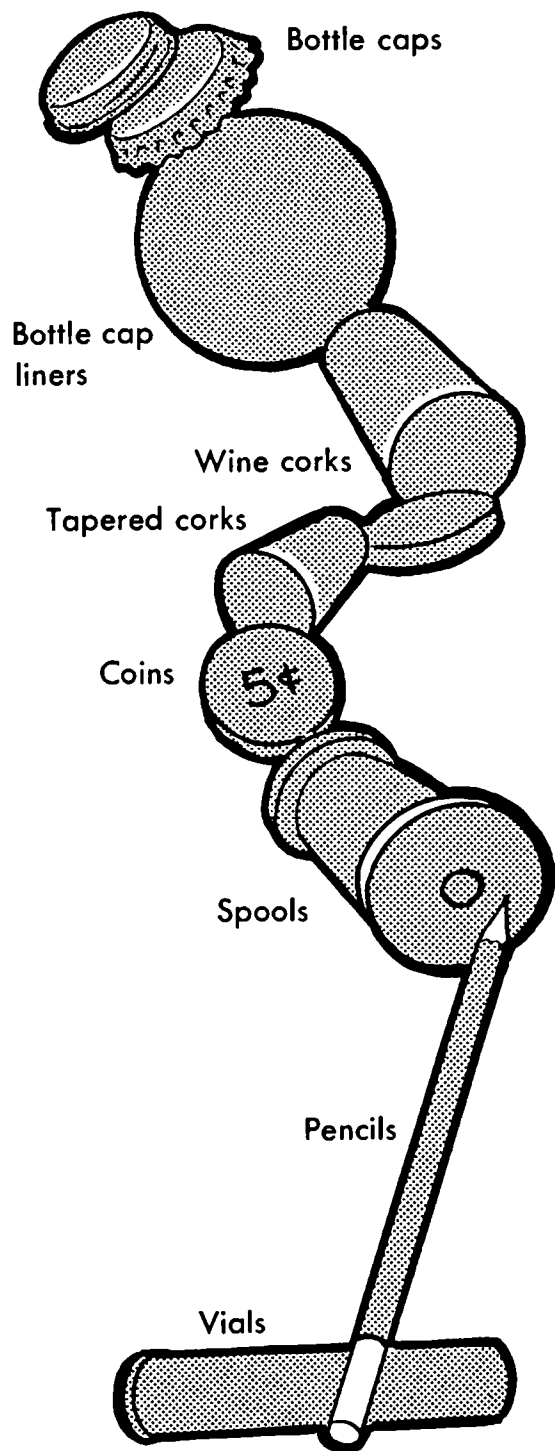


Sheet metal base



Plastic bottle base

Change the Material of the Rotor



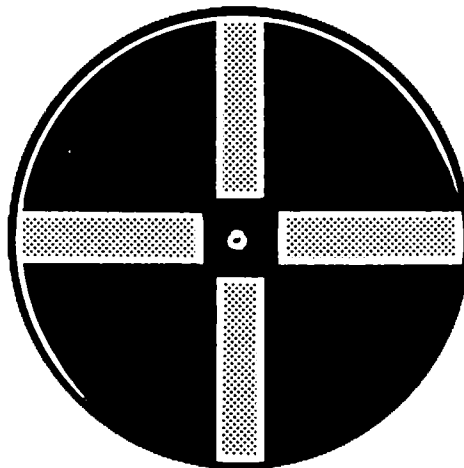
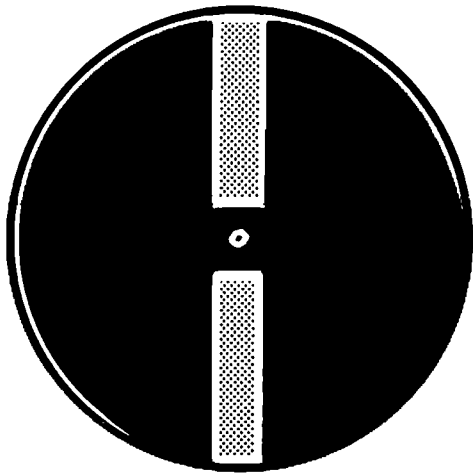
You have a wide selection of materials from which to make your rotor:

- Bottle caps
- Liners from bottle caps
- Wine corks
- Tapered corks
- Flat disks from wine corks
- Poker chips
- Checkers
- Spools
- Broom handle sections
- Wooden dowels
- Disks from tree limbs
- Wooden buttons
- Plastic foam disks
- Pencils
- Toy wheels
- Pulleys
- Gears
- Coins and slugs
- Plastic vials
- Plastic test tubes

Possible materials for rotors

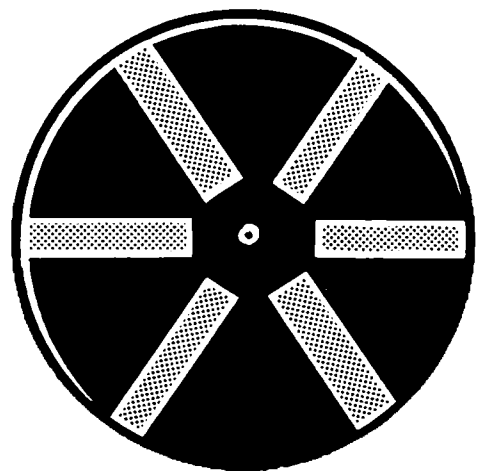
Change the Number of Rotor Magnets

See page 77 for suggestions on changing the commutator. These two changes must be coordinated.

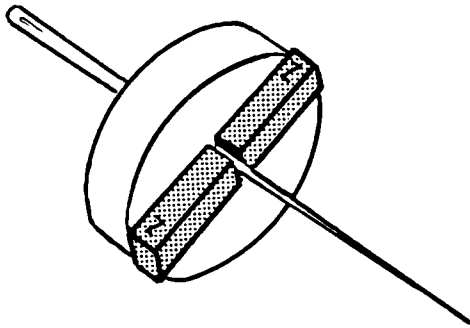


If I changed the external or outside pole of each magnet. . . .

If I switched the polarity of just half of the magnets. . . .



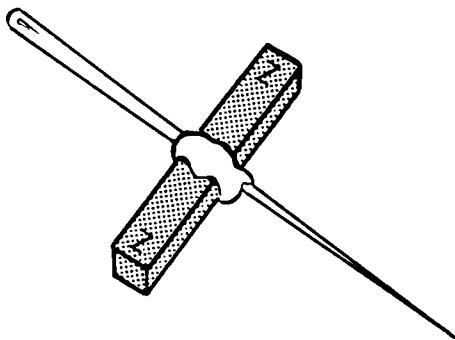
Change the Position of the Rotor Magnets



Held by cork and glue

If I glued the bar magnets end to end on the cork. . . .

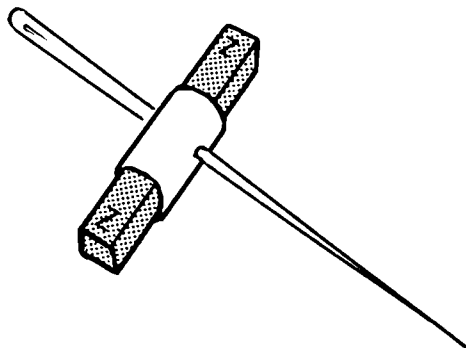
If I just fastened the two magnets end to end with quick-drying glue. . . .



Held by glue alone

If I fastened the two magnets end to end with a tight rubber tube, plastic tube, or soda straw tube. . . .

If I changed the polarity of the magnet ends to be opposite. . . .

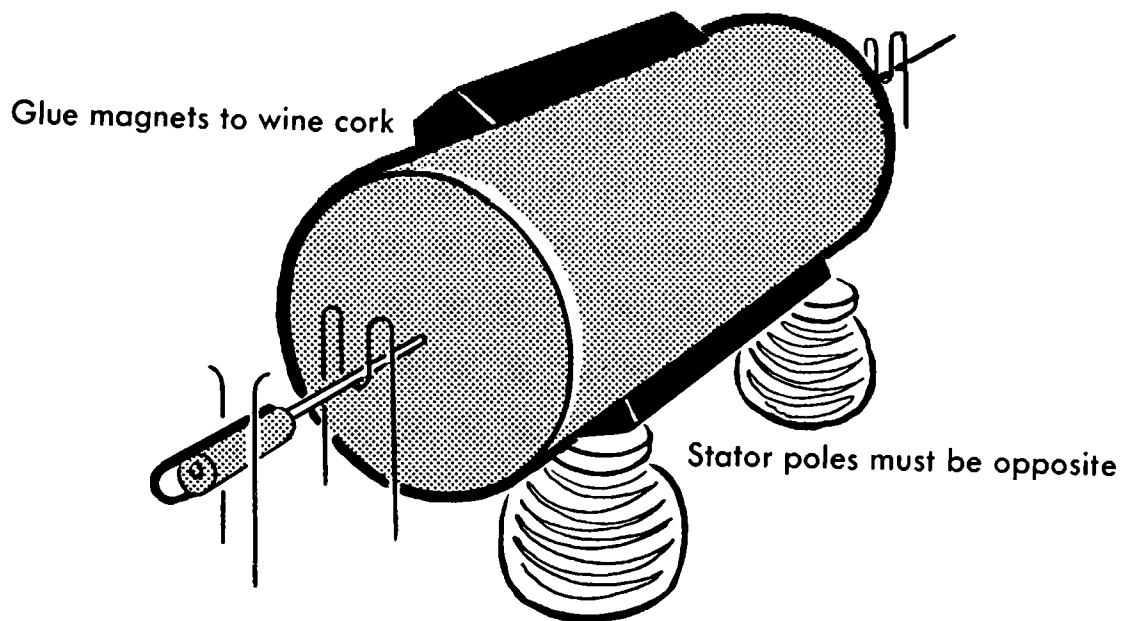


Held by tube

If I placed the two magnets parallel and close to the axle. . . .

Change the Attitude of the Rotor Magnets

Be sure to wind the stator or field coils in opposite directions so that their polarities will be opposite. Would this motor work with one stator? Where would you place it? Could you use more than two rotor magnets? Remember to make only one change at a time so that you can tell what makes the greatest difference in the performance of the motor.

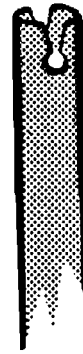


Place magnets parallel to axle

Change the Bearings

If I changed to soda straw bearings. . . .

Cut the desired lengths with a razor blade or with scissors. Melt the cradle slots with a hot nail. Drill the bearing post hole by twisting a sharp pencil into the foam base.



Soda straw bearing

If I drilled a bearing hole into the metal eraser holder of a stub pencil. . . .

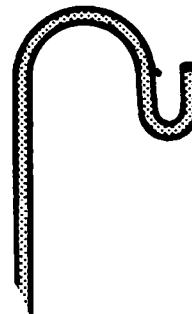
A V slot can be cut to the bearing hole with tin snips or with a file.



Eraser holder bearing

If I went back to S-bent wire cradle bearings, which I used for the Mini Motor. . . .

If I compared a wide, loose cradle with a narrow, tight cradle. . . .



Bent wire bearing

Change the Axle

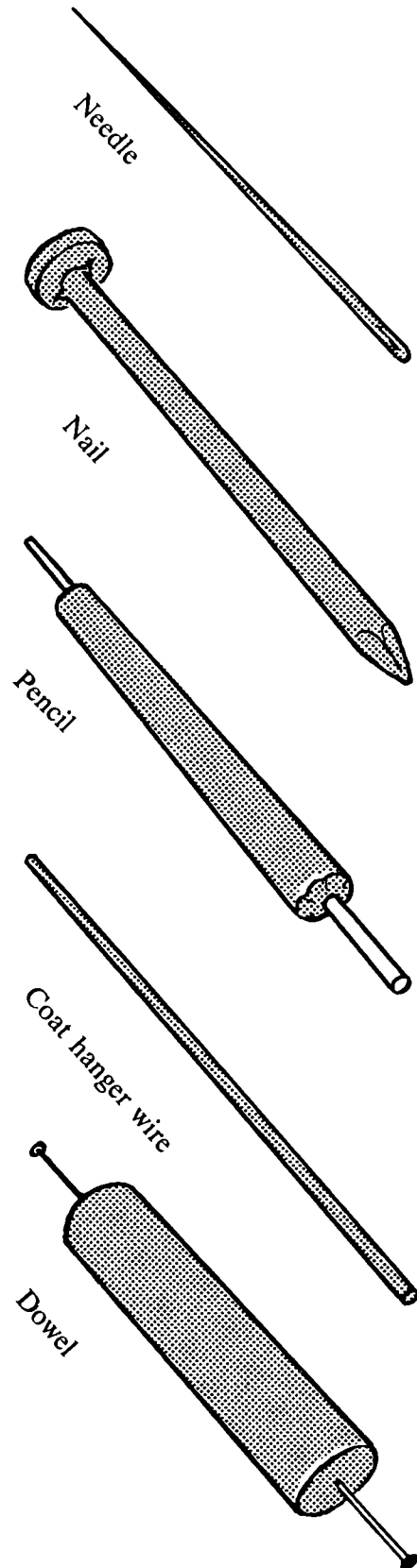
Large needles are best because their hard steel surface reduces friction. Ask for large darning needles. The best are the longer upholstery needles, which must be purchased at upholstery stores.

Nails are easy to get. But they must be new and shiny. You should file off the press mark under the head. Get a variety of lengths and diameters.

Coat hanger wire is good when it is straight. Rolling it on a table is the best test for straightness. Always straighten wires by rolling them under a book cover.

Pencils make good axles. The graphite of the lead is a natural lubricant.

Pins and small needles work well for axles if you can center the pair. They are especially good for cork and wooden rotors.



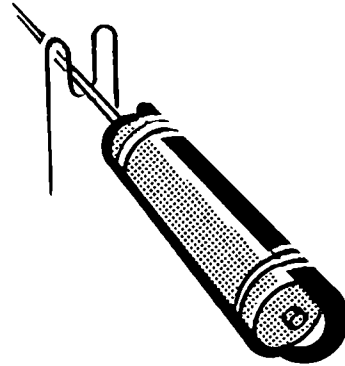
Change the Material of the Commutator

Painting the sides of the axle with fingernail enamel is a quick way to make a commutator. However, the hot sparks soon burn this off when you get too enthusiastic about running your motor.

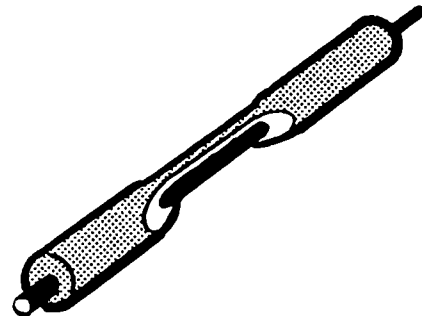
The most commonly used commutator for experimental motors is a loop of copper wire bent over masking tape which has been wrapped around the axle. Secure the copper wire with thin tape strips or with thread and glue.

Plastic insulation can be made into a good commutator. Strip it from copper wires after shaping it, and slip it over your axle.

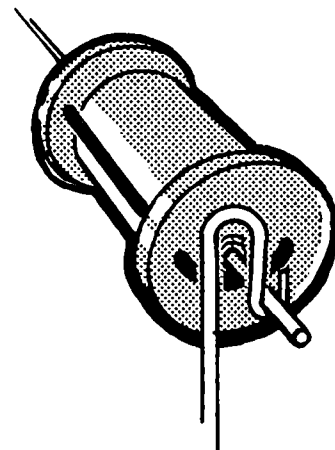
Spools and corks are good for holding the rotor magnets, and they make good commutators at the same time. Wind a tape bushing around the needle axle to make it fit the large hole of a spool.



Loop of wire commutator

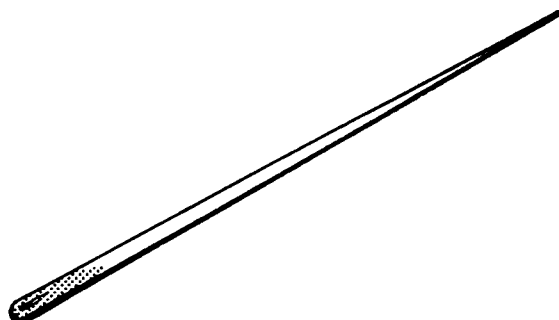


Plastic insulation commutator

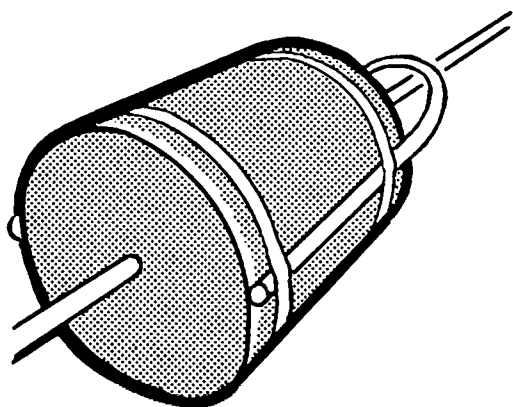


Spool commutator

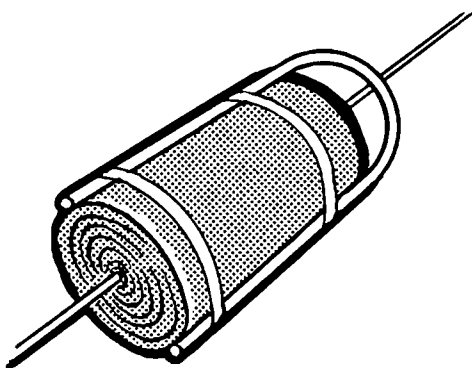
Change the Diameter of the Commutator



Enamel on needle or wire



Large cork or wooden spool



Tape is most adjustable

Would there be a difference in the amount of friction produced by a small or a large commutator? Would there be a difference in the amount of leverage used to turn the axle? Which size would enable you to time multiple rotor magnets best?

Fingernail enamel painted on the sides of the axle makes the smallest commutator. The part of the axle which should remain bare can be scraped clean with a razor blade.

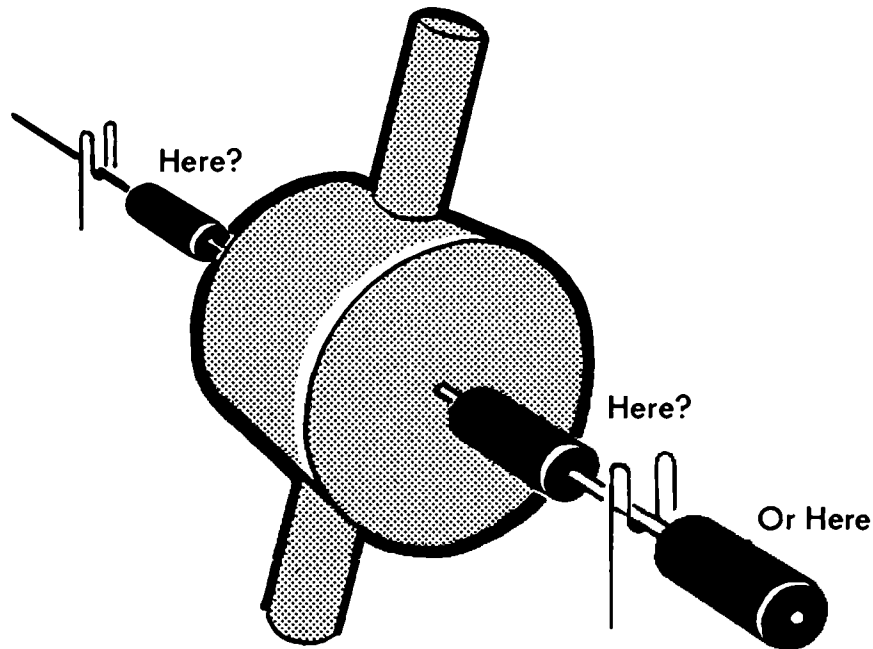
Masking tape is chosen most often for the commutator. It is easy to change its diameter.

Wooden spools serve well as large commutators, and they can hold many rotor magnets easily.

Corks, even when tapered, work as well as spools. The straight wine corks are especially good for large commutators.

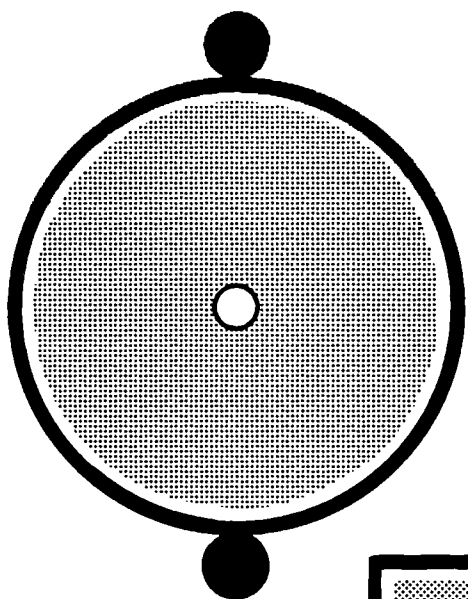
Change the Placement of the Commutator

Should the commutator be inside or outside the bearing posts? On which side of the rotor magnets would the commutator be most convenient? What are the advantages and the disadvantages? With which placement is it easiest for you to adjust the brushes? When you want to spin the axle with your fingertips, do you ever wish that you had placed the commutator differently? Now is a good time to experiment with these changes.

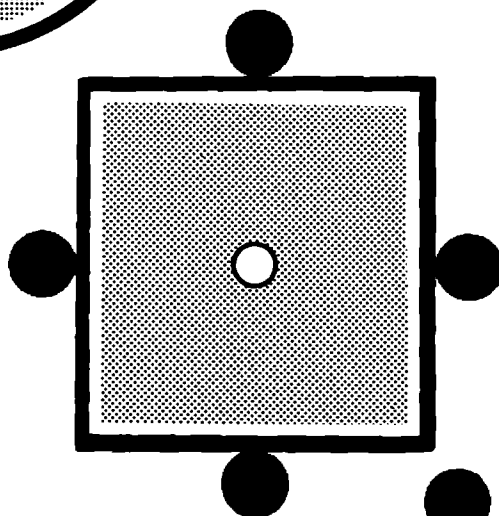


Where should the commutator be placed?

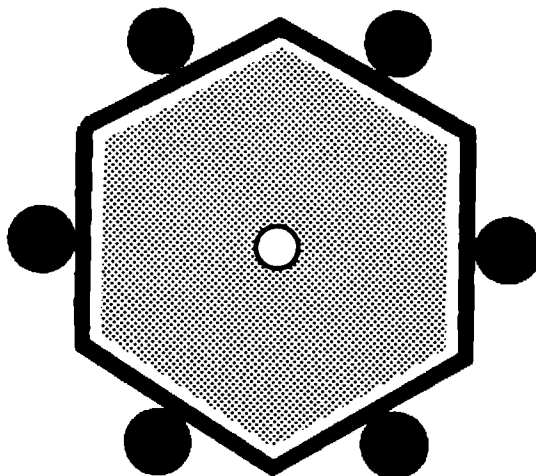
Change the End-View Shape of the Commutator



Some shapes make it easier to space the multiple conductor wires of the commutator when you use more than two magnets on the rotor.



Pencils are the easiest-to-find hexagonal objects. Corks can be cut to the desired shape most easily. Wood is the most durable.

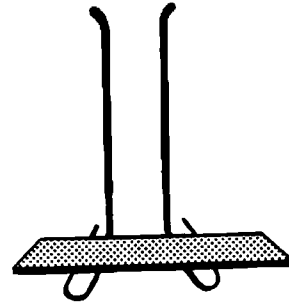


Change the Method of Securing the Brushes

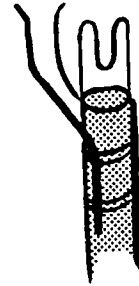
The simplest method of securing the brushes is to bend feet and to tape them to the base. They can also be fastened with flat-pounded copper wire staples.

You can fasten the brush wires to the bearing post with rubber bands, with tape, or with thread and glue. Brushes can be threaded through needle holes in a cork. The cork can then be glued to the base.

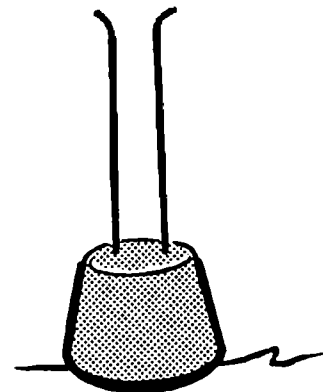
You may want to do it one way for your experimenting and another way when you make a permanent motor. Which will be best for the Super Motor you will be building soon?



Fasten with tape



Fasten to bearing post

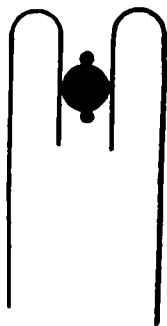


Support with cork

Change the Shape of the Brushes

If I doubled the amount of springiness by bending the ends of the brushes downward. . . .

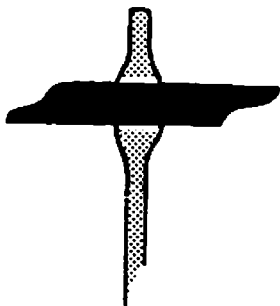
This also would make it easier to change the rotor.



Increase springiness

If I enlarged the contact area by flattening the round copper wire with a hammer. . . .

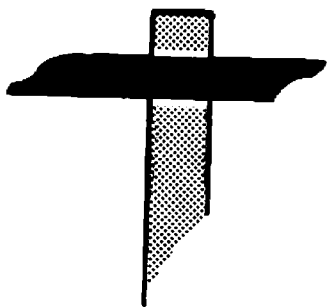
The flat area also could be shaped to fit the spinning commutator better.



Flatten the brush wire

If I used just a flat wire for the brushes. . . .

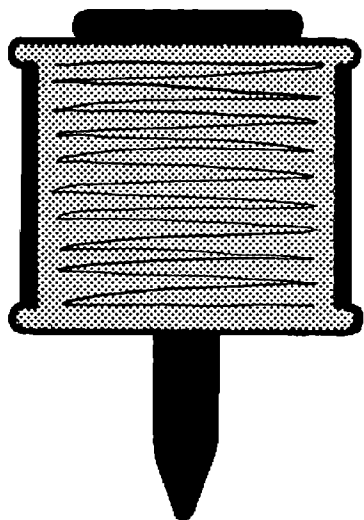
Have you tried brass wire in place of the copper wire yet?



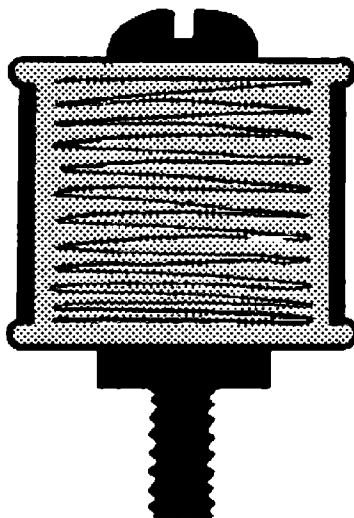
Buy flat wire

Change the Core of the Stator Coil

Wrap your coils with strips of aluminum foil and waxed paper before you wind and glue them together. This will enable you to slip the coils on and off the cores easily in your experimenting. You can then use them over and over again.

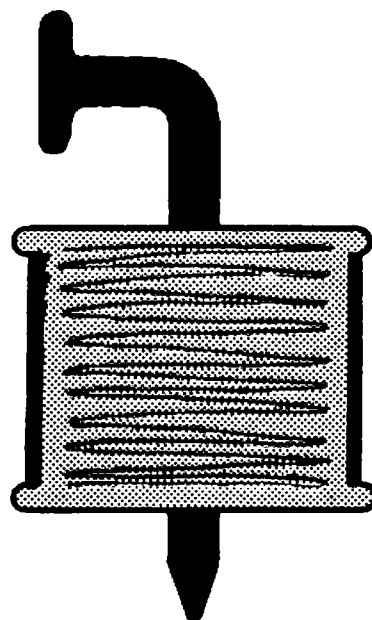


Roofing nail core



Bolt-and-nut core

Nails can be shaped to place the magnetic poles closer together. Bolts and nuts hold coils more securely in place. All are easy to use with the plastic foam bases.



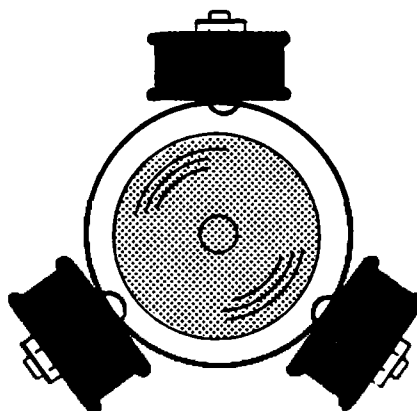
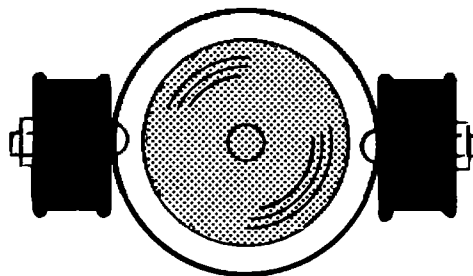
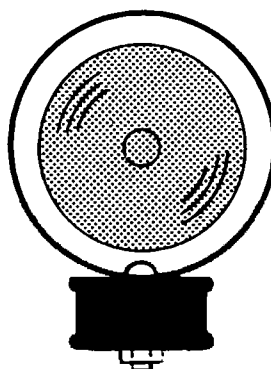
Bent nail core

Change the Number of Stator Coils

You can always cut plastic support rings out of round plastic bottles. Detergent bottles and medicine bottles both work well. Leave the bottom of the bottle in to support one end of the axle.

Are one, two, three, or four stator coils best? Would this provide more magnetic strength? Or would there be too much resistance in that much wire for a low-voltage dry cell? Your motor will tell you.

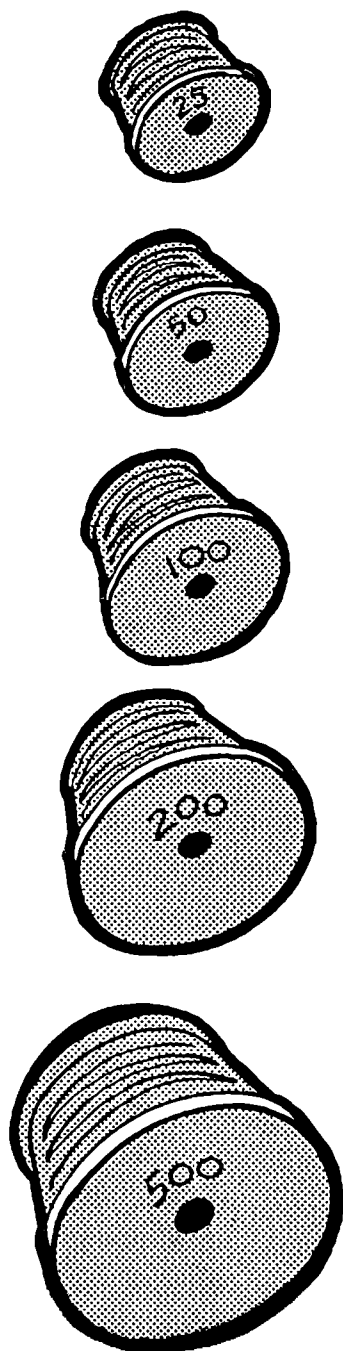
Be sure to mark the number of turns on each coil with tape and a felt pen.



Change the Number of Turns on the Stator Coils

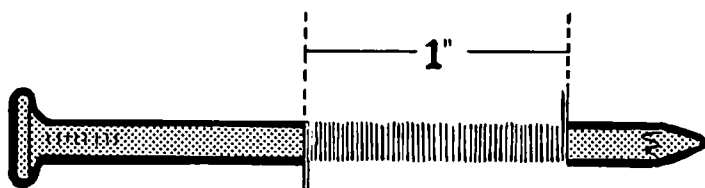
Make interchangeable coils of 25, 50, 100, 200, and 500 turns. Wind some loose aluminum foil and waxed paper strips around the bolt or large nail to be used as a core. Wrap and glue a couple of turns of note card paper over this. Use the cardboard liners from small bottle caps, or cut disks from milk carton cardboard for the ends of the coil forms. Glue each layer of coil winding so that the coil will hold its shape when finished. The waxed paper and aluminum foil should be removed from the center, allowing the coil to slip easily on and off the iron cores.

Mark the number of turns on each coil with a felt pen. You will want to use the coils over and over again in your experimenting.



Change the Size or Gauge of the Wire

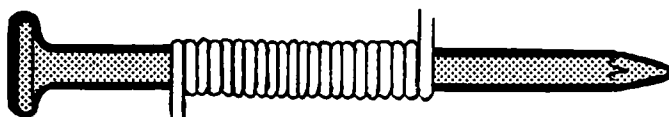
What size of wire is best? The size of wire is measured in turns per inch without insulation. Be sure to use the same length of varnsh-insulated wire for each coil. Wind your coils so that they will slip on and off the cores easily. Mark the gauge number on each coil. Store each kind of coil in a separate milk carton filing box.



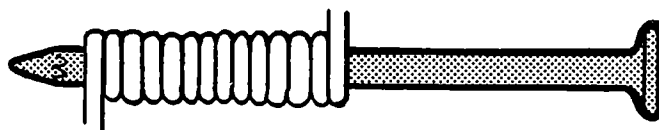
#50 gauge hair wire



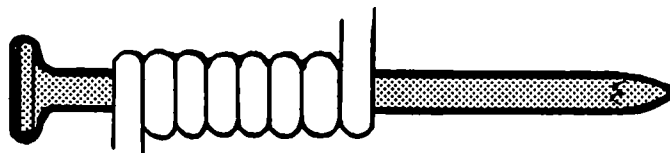
#28 gauge magnet wire



#22 gauge magnet wire



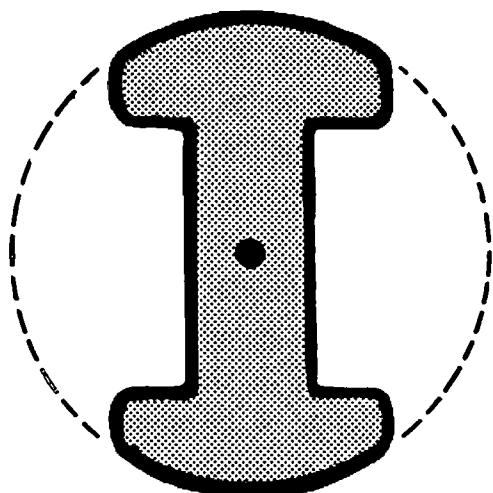
#14 gauge bell wire



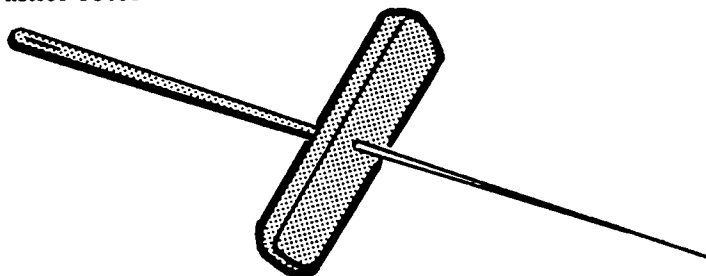
#8 gauge house circuit wire

Change to a Non-Magnet Rotor

Do rotors have to be magnets? Would a stator magnet attract just an iron rotor and make it spin? Saw and file a fender washer to the shape shown at the left. Fender washers which have smaller holes are obtained at hardware stores. Masking tape is a fine bushing to wrap around the axle to make the rotor fit snugly.

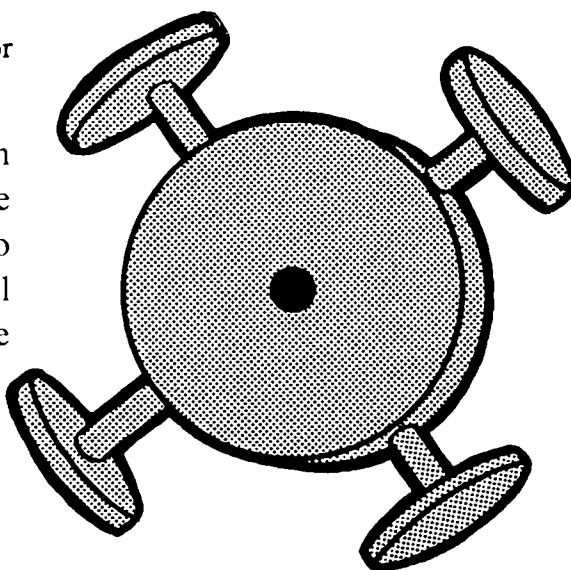


Fender washer rotor



Iron bar rotor

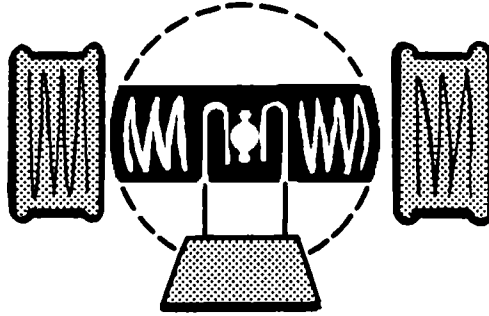
Cut or saw and drill a soft iron bar. Roofing nails with their large heads are good when hammered into a drilled spool. A tape bushing will make even a spool fit a small needle axle.



Roofing nail rotor

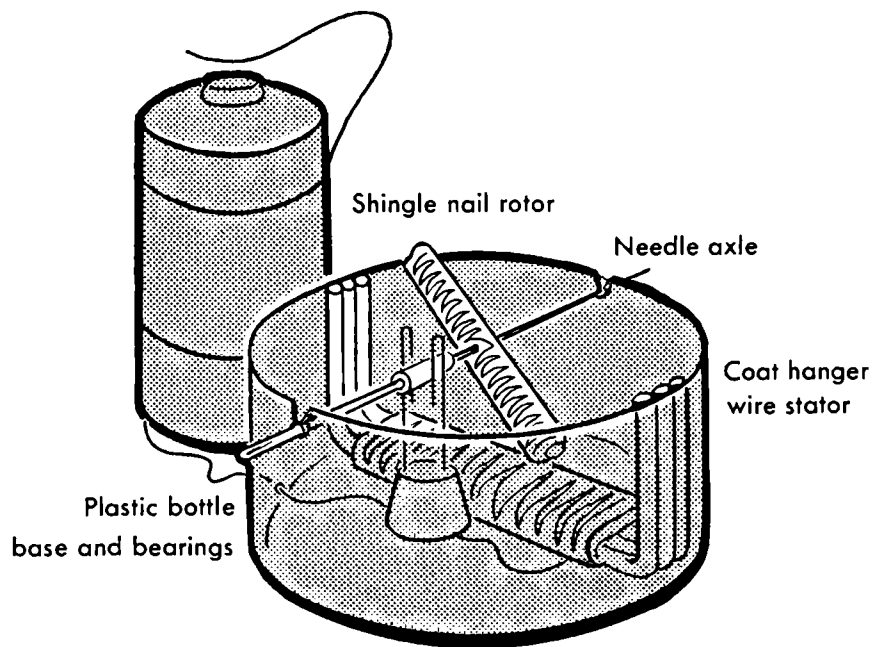
4

The Maxi Motor



The Maxi Motor can be made as large and as powerful as you want it. It is completely electromagnetic. It does not depend on any permanent magnets.

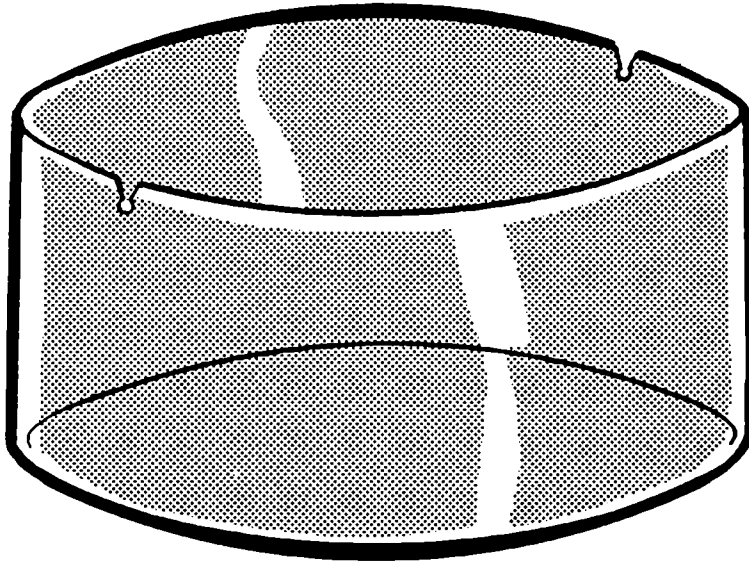
This Is the Maxi Motor



The Maxi Motor

Build this all-electromagnetic motor on a small scale first so that you can experiment with the same materials that you have been using. However, you will soon be able to make this motor as large and as powerful as you want if you have enough wire and iron to build the electromagnets.

Make the Base and the Bearings First



Plastic bottle base and bearings

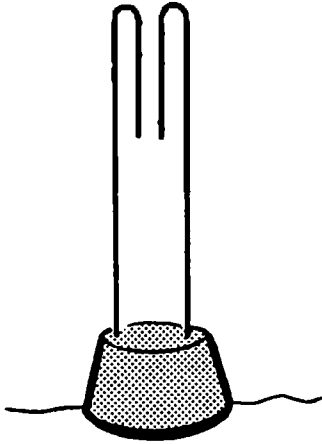
Once again, each step in the construction will be described on a separate page. Make the base first because the cork holder for the brushes must be glued to the bottom. This then can be drying while you build the rest of the motor.

Get a round plastic medicine bottle which is about one and one-half to two inches in diameter. Pharmacists throw away a box of bottles like this every day. Cut away the top with tin snips, a razor, or a knife until it is about one and one-half inches high.

Melt a hole with a hot nail through each side for the axle bearing. Cut a V downward to the hole to make it into a cradle bearing. If the bottom of the V is cut slightly smaller than the hole, the axle can be pressed down and will not pop out when running too fast.

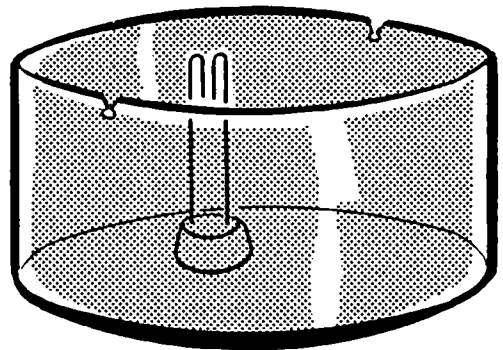
Build the Brushes

Cut a small cork in half. Then strip two inches of varnish from the ends of two 8-inch wires. Push two needle holes through the cork, and thread the two bright wires up through them. Bend the base of each wire flat under the cork to its side.



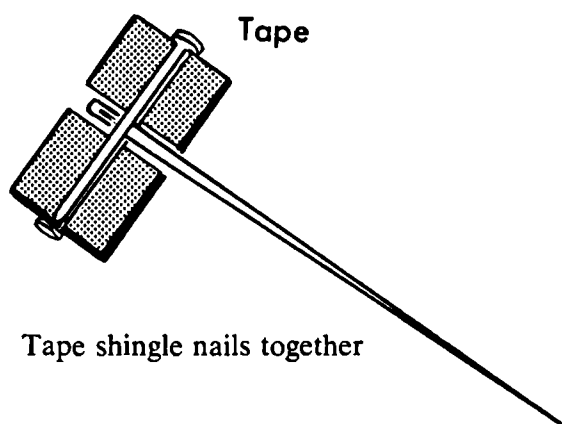
Support brushes with cork

Look again at the illustration of the Maxi Motor to see where you will place the cork in line with the bearing holes. Put a generous amount of glue on the cork and press it into place. Drill two holes with a hot nail in the base and tie the cork to the bottom with a short piece of copper wire.

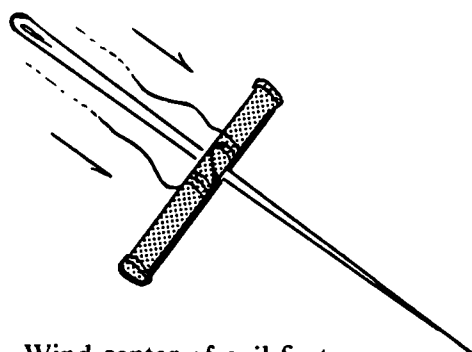


Glue cork to base and tie with wire

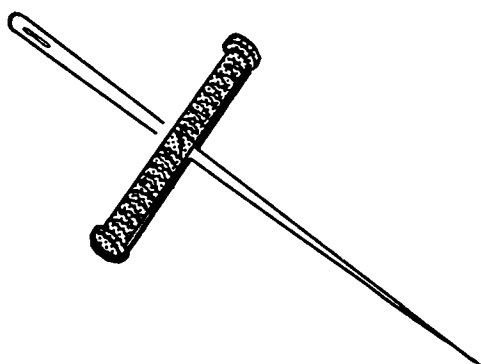
Make the Rotor or Armature



Tape shingle nails together



Wind center of coil first

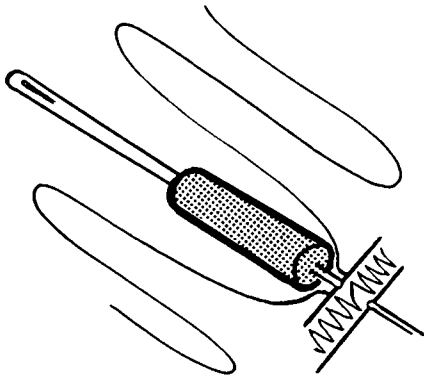


Wind twenty turns on each side

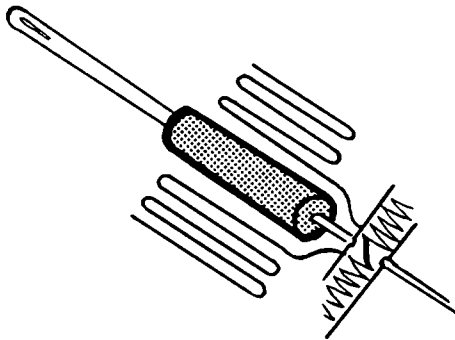
Lay the flat eye of a needle between two shingle nails on two $\frac{3}{8}$ -inch-wide strips of masking tape as shown. Wind the tape around the two nails to keep them parallel.

Making sure that the axle is still centered, lay the middle of a 30-inch-long insulated magnet wire diagonally across the joint of the axle and the rotor. Wind three turns on each side and stop. Check once again to see that the axle is still centered. Stand the needle on its point and press the rotor down to the middle of the axle. The joint is now very tight, and it will become tighter as you wind more turns of wire onto the rotor. Continue winding until you have made twenty turns on each side of the rotor.

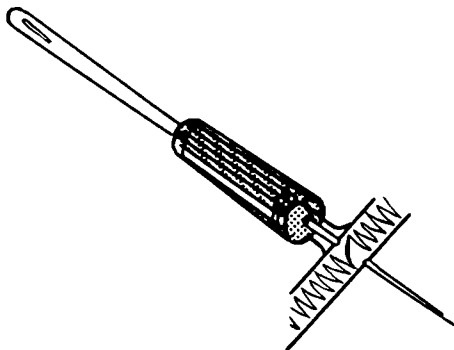
Build the Commutator or Spinning Switch



Strip the insulation



Bend the terminals into loops



Be sure to keep the terminals separated

Wind three or four turns of tape around the axle. Strip the varnish off the lead wires of the rotor with a sharp knife. It may help to soften the varnish with paint remover or by burning it with a match. The lead wires must be bright and clean.

Bend or double the lead wire three or four times on each side to make a broad terminal contact.

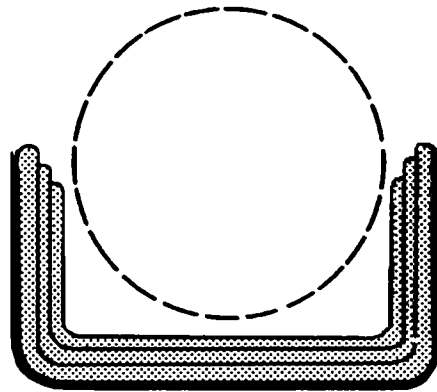
Lay one of the folded terminals on the top half of the commutator tape. Put the other half on the bottom side. Secure the folded terminals in place with tape, or tie them with thread and add glue. The two terminals must never touch each other. This spinning switch must reverse the polarity of the rotor magnet.

Wind the Stator or Field Coil

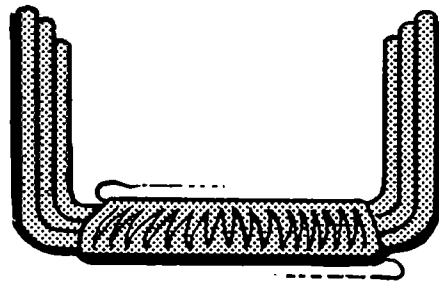
Bend three coat hanger wires into a U shape so that the rotor will be close but will spin freely within it. The top of the U should be even with the top of the plastic base.

Next, wrap one hundred turns of magnet wire around the horizontal base of the U-shaped stator. Leave 6-inch leads on the ends of the coil.

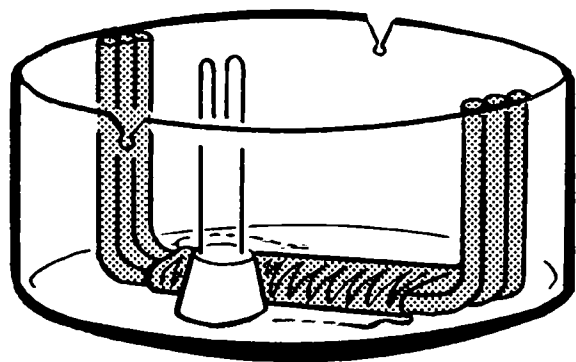
Tie the stator coil to the base through holes which have been drilled through the bottom with a hot nail. Tie the stator with short wires which can be twisted under the base. The bottom of this type of bottle is usually arched, leaving plenty of room for the twisted wires.



Bend coat hanger wire over wooden block



Wind stator coil around the base of core



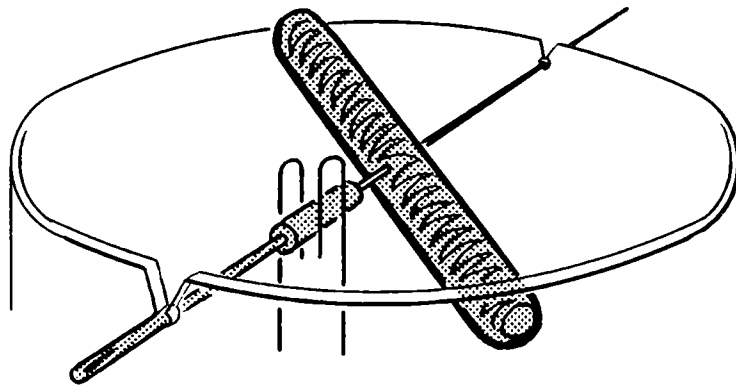
Bind stator to base with wire

Balance the Rotor

The rotor of an electric motor must spin effortlessly. It can do this much better when it is well balanced. Balance the rotor first on the handles of a pliers. Then spread the brushes slightly and spin-test it in the bearings.

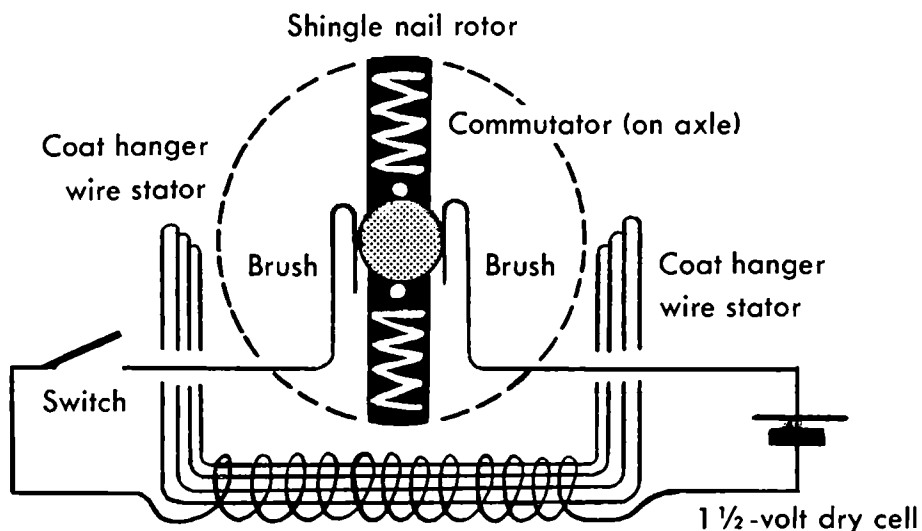
Adjust the brushes next by straightening them where they come up from the cork base. The space between the brush terminals should be slightly less than the diameter of the commutator.

Put the rotor in place now, and spin it a few times in the brushes. The frictional drag of the brushes will slow it slightly.



A balanced rotor is extremely important to a good motor

This Is the Circuit for Your Maxi Motor



Maxi Motor schematic circuit

Now hook up the circuit of your Maxi Motor and watch it spin. Join one end of the stator wire to the nearest of the brushes. The other brush wire and the other end of the stator coil will be connected to the terminals of the dry cell. It is always wise to use a little extra power to adjust this motor. After being adjusted, the motor should run on one and one-half volts of power.

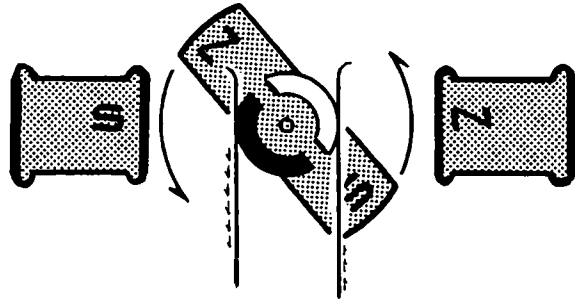
If, by chance, your motor does not run immediately, check to see if you really have a complete circuit. Also, you can change the timing of the commutator by holding the axle with a pliers as you twist the rotor just a little to one side and then slightly to the other side. Your motor will tell you which position is best.

Check for Polarity Reversal in the Rotor Magnet

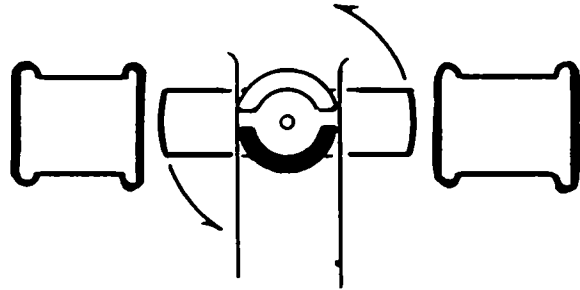
The commutator of the Midi Motor in the last chapter merely switched the electricity on and off for the electromagnetic stators. The power was off half of the time that the motor was running.

The commutator of this Maxi Motor will serve two functions. First, it will serve as a switch again. And secondly, it will reverse the polarity of the rotor magnet so that the motor can use power 100 percent of the time. The Maxi Motor, therefore, should be twice as powerful from the beginning.

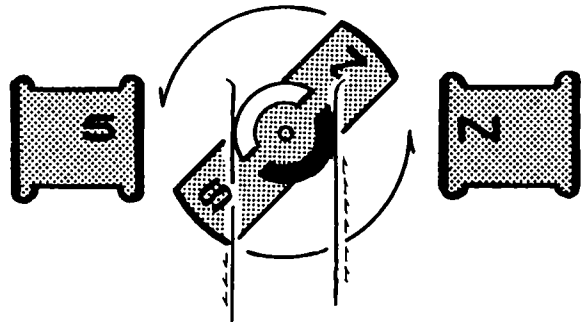
The drawings on the right explain how the commutator does this. Note especially how the direction of current flow is reversed in the rotor alone as it enters first one side of the commutator and then the other.



Opposites attract



Changing



Likes repel (Polarity has changed)

Experiment Now with Your Maxi Motor

You can repeat many of the experiments which you did with the Mini and the Midi Motors. You should now be adept at predicting what differences will be seen with each change. Remember always to say specifically what will happen before you start the motor. If you are wrong, experiment a little longer with that particular condition or property until you understand it better.

On the following pages a few changes will be suggested just to encourage you to think more about the relationships of the different parts of your motor. It is up to you to carry on the experimenting from there. Generate your own ideas about how to explain what is happening. Then test your ideas right away with predictions to see how well they match the truth.

It is hoped that by now you have been able to get a few more tools and materials to use. Alligator clips soldered to the ends of a few short wires will speed your experimenting many times. Taping loose wires to the table or the base will prevent connections from loosening and will give you more freedom to work. Connect the lead wires from different components with a Fahnestock clip. You can solder the connections when you have finished experimenting. Use cradle bearings as long as you are experimenting, even though the axle might pop out occasionally. Always design a motor part so that it can be changed and interchanged.

Change the Method of Securing the Brushes



Tape to the base



Staple to the base



Glue to the base



Support with half cork



Screw to the base



Rubber band to bearing post



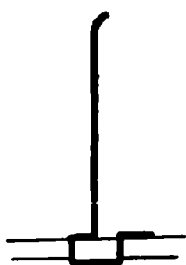
Solder to thumbtack



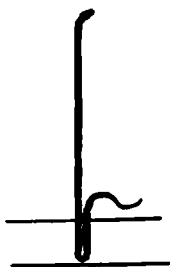
Solder alligator clip to tack



Solder Fahnestock clip to tack



Bend through holes in base



Double bend into hole



Bend around nail to produce spring

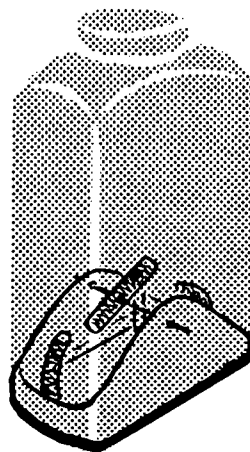
Change the Base

Plastic bottle bases do not need to be round. Rectangular bottles can support the axle sideways or longways. The axle can even be placed diagonally to the corners.

You could use a pet food can for a base. What are the advantages and the disadvantages of a metal base?

Cafeteria milk cartons come in many sizes. They can be cut easily with a razor blade or with a scissors.

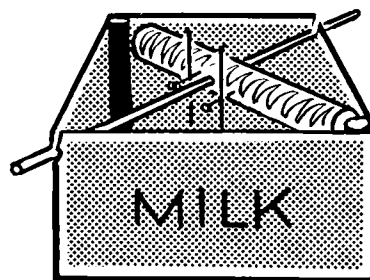
Plastic foam trays and blocks make good bases for the Maxi Motor, too. How about a wooden base for a change?



Try different kinds of plastic bottles

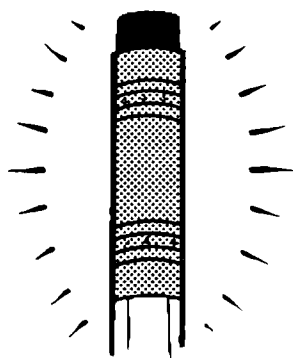


Use pet food cans

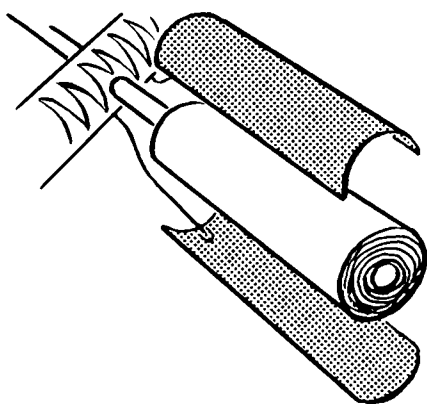


Milk cartons are easiest to obtain

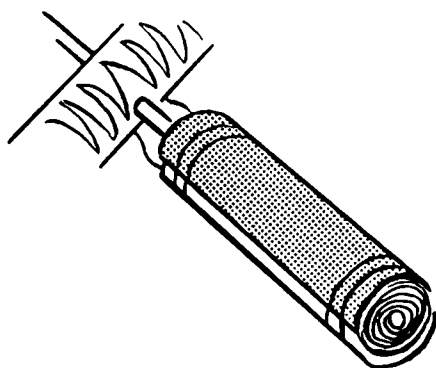
Change the Commutator Surface



Clean varnish off tube while still on pencil



Wind masking tape around axle



Secure the curved plates with tape or thread

Make use of the tubing which holds the eraser to your pencil. Sandpaper the tube bright and clean of varnish before you take it off the pencil. Cut the tube in half the long way with a file or with tin snips.

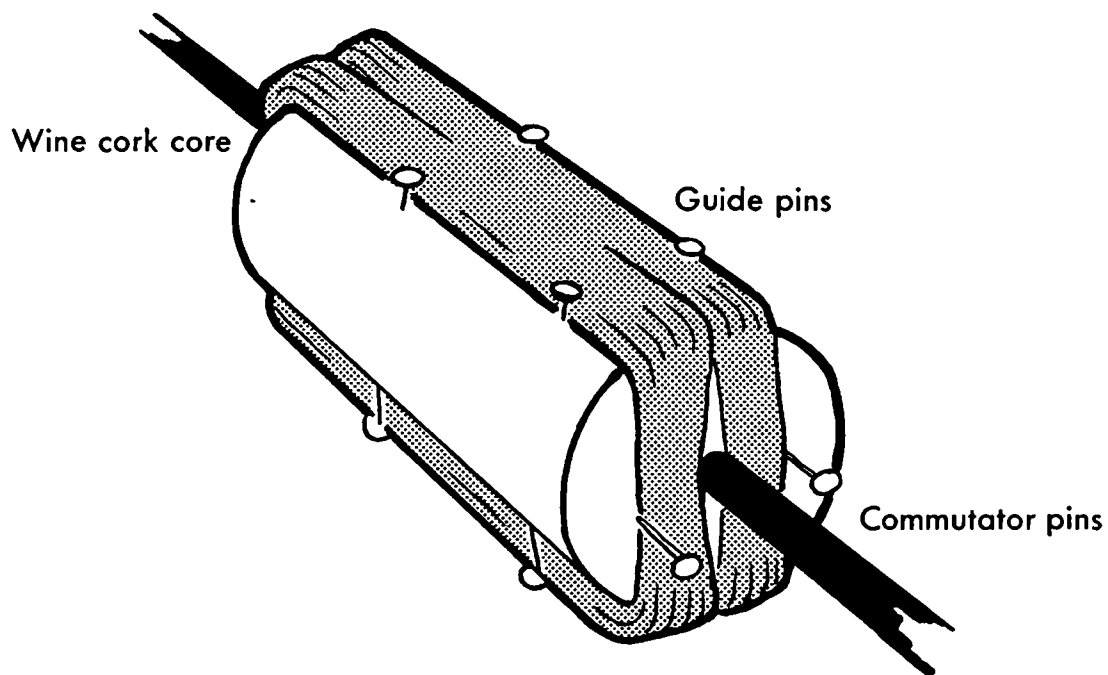
Wind masking tape around the axle until it is the diameter of the pencil plus one extra turn. The lead wires from the rotor coil can be laid on the tape, and the half-round tubes can be pressed over them. A still better method is to connect them by soldering.

Bind the half tubes to the masking tape with thread and glue. The purpose of the extra turn of tape is to put space between the half tubes. They must never touch.

Could aluminum foil be used for a commutator surface? Remember that the space should be in line with the rotor coil and that the two halves must never touch.

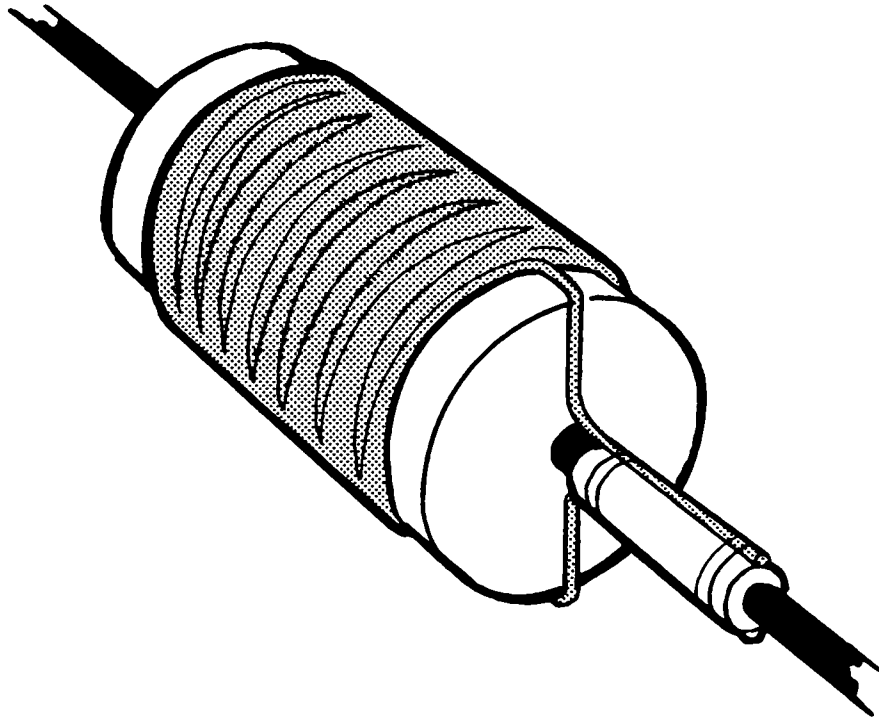
Change the Commutator

Just for fun, now try this easy-to-make commutator, even though it may not look as good as some of the spinning switches you have been making. Two pins stuck into a wine cork or wooden spool form this simple commutator. Wrap the bare ends of the coil wire around the pins a few times. The coil is usually wound the long way on the cork.



Two-pin commutator

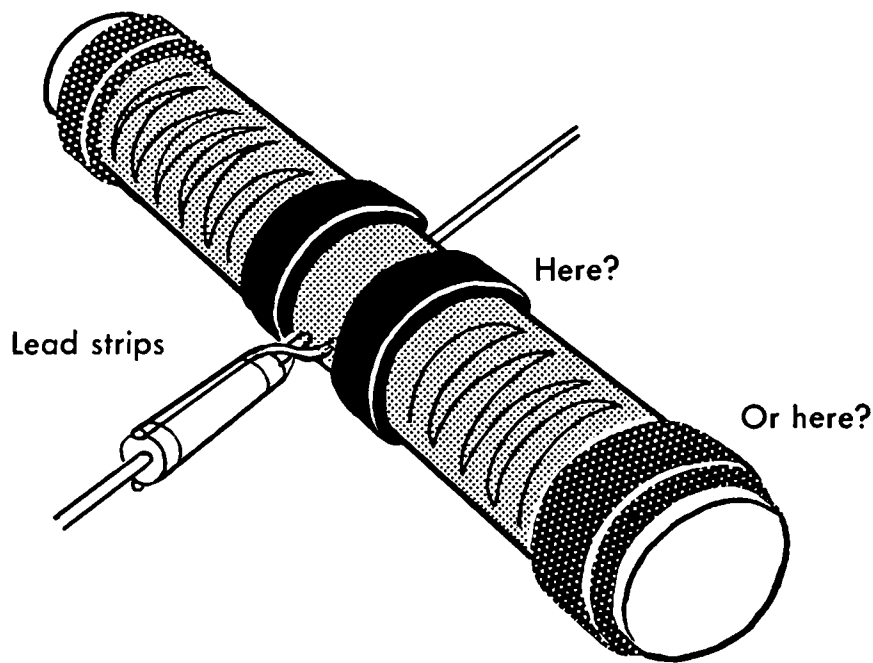
Change the Attitude of the Rotor Coil



Spiral-wound rotor

Do the coil wires always have to be parallel to the axle? It would be easier to spiral the wire around the rotor as you wind it. Why don't you try and see? Use wine corks and wooden spools for coil forms. The spools may require a tape bushing at each end to make the hole fit the axle. Use masking tape to pad the axle enough to fit the hole of the spool.

Change the Position of the Weight on the Rotor



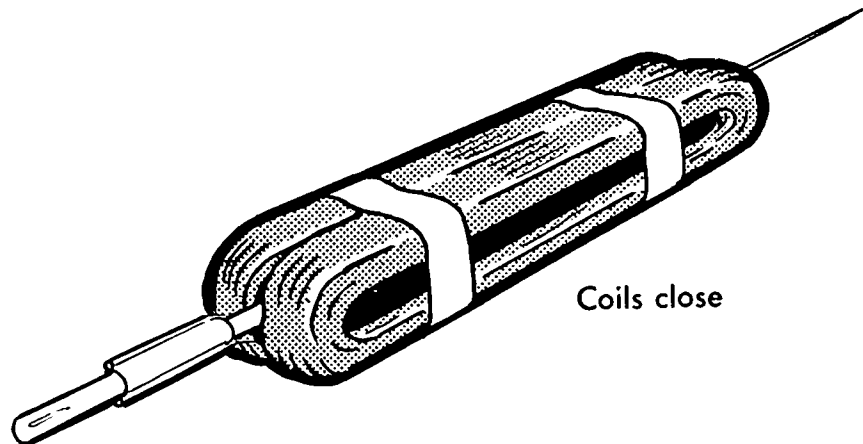
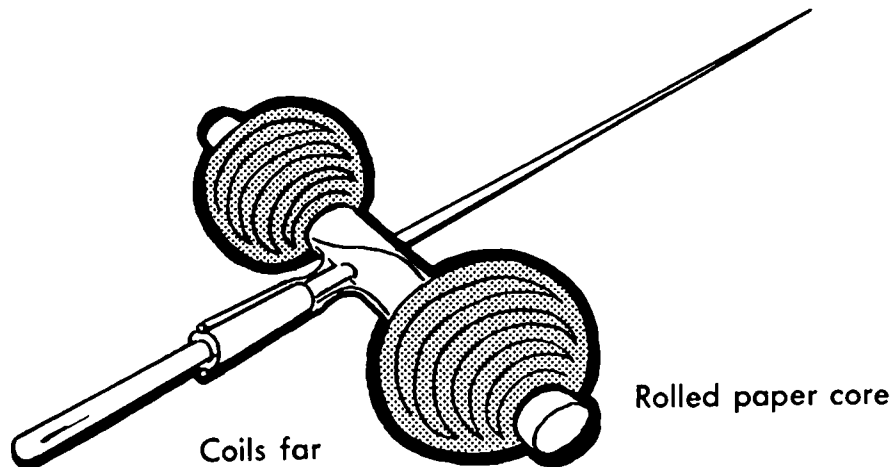
Where should the weight be placed?

Would a rotor spin better with most of its weight close to the axle or far from the axle? Secure the lead strips in place with tape, or tie them with thread and glue. Wine cork seals make good weights. Solder wire and even heavy copper wire have been used. Be sure that the sides of the rotor are balanced exceptionally well before you start this experiment. Heavier rotors must be balanced best.

Change the Position of the Rotor Coil

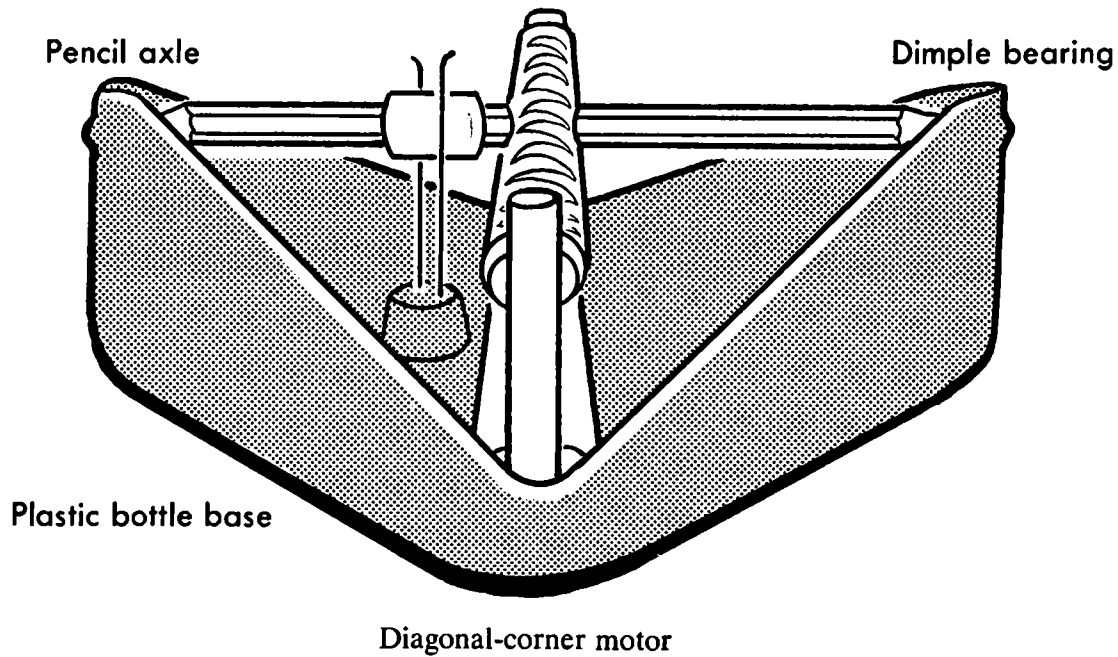
Should the rotor coil fit closely to the axle, or should it reach far out? Which would have the most leverage to turn or torque the axle? Which would bring the poles of the magnetic fields closest together? Here is another way to test your ideas.

Be sure to balance the rotor until it spins effortlessly.



Should the coils be close to or far from the axle?

Change the Axle

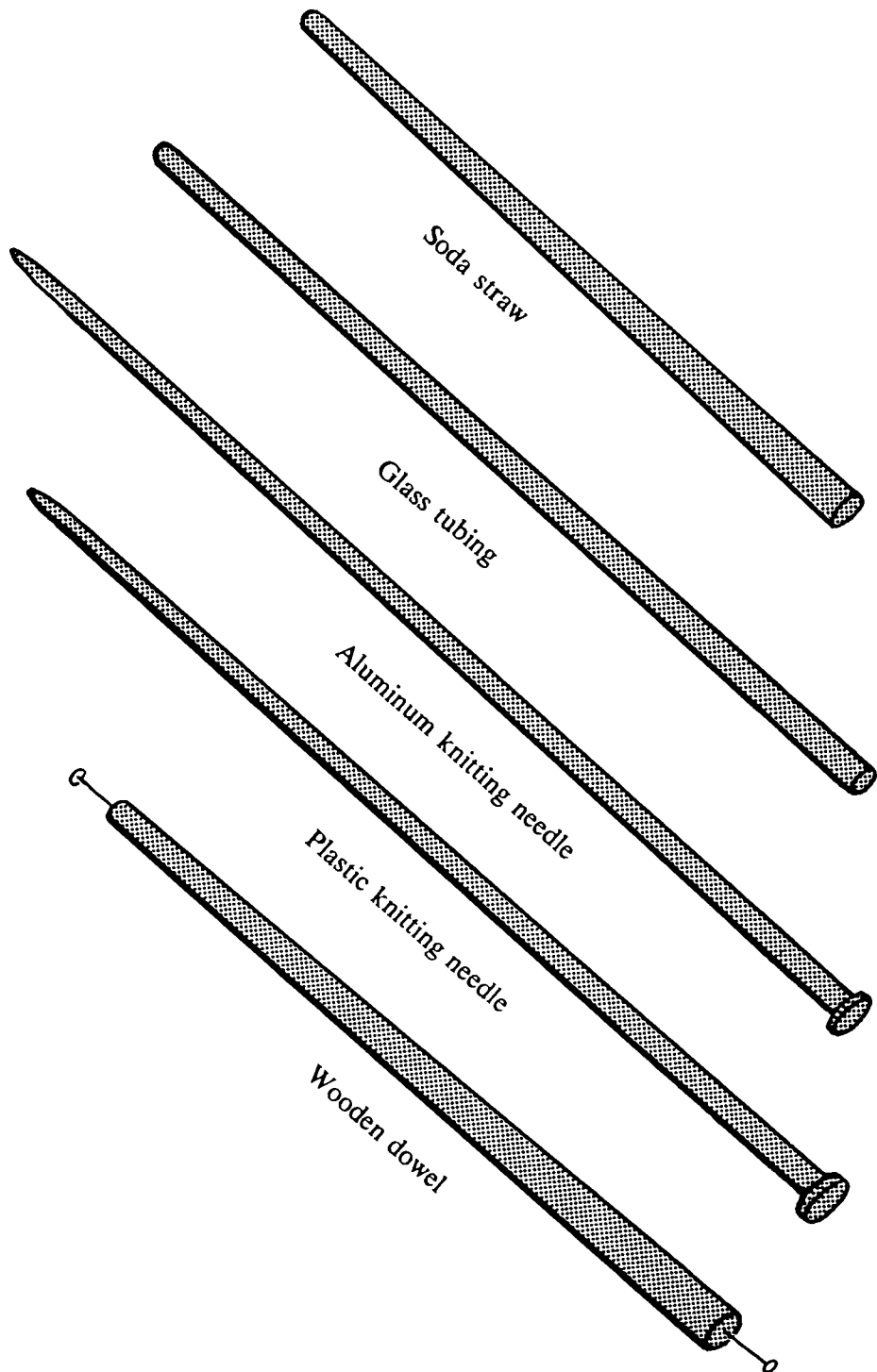


Hexagonal pencils have a natural shape for a single or a triple commutator. They are very easy to obtain. There are two more good reasons why you should try them as axles in your experimenting with electric motors:

First, the lead lubricates the bearing well with its natural graphite. Dimpled bearings can be used as well as cradles or holes. The dimples are made in the diagonal corners of square plastic bottles by turning the point of a hot nail where you want the bearing located.

Second, an added advantage of the pencil as an axle is that holes can be drilled easily for a nail or coat hanger wire core for the rotor coil.

Change the Axle



Change the Stator Magnets

It is intriguing to watch a motor spin inside a clear plastic tumbler. Use the flat coils which you made for your Midi Motors as your stators. Melt holes in the tumbler with a hot nail, and bolt the coils to the clear plastic. Shape the cork with sandpaper before you glue it to the inside of the tumbler. The cork will hold the brushes against the commutator. One lead wire from each stator can be made into a brush. The other lead wire will be attached to the power supply. Be sure that your stator magnets have opposite polarity. After you have made this motor run, could you redesign it to run in an inverted plastic tumbler?

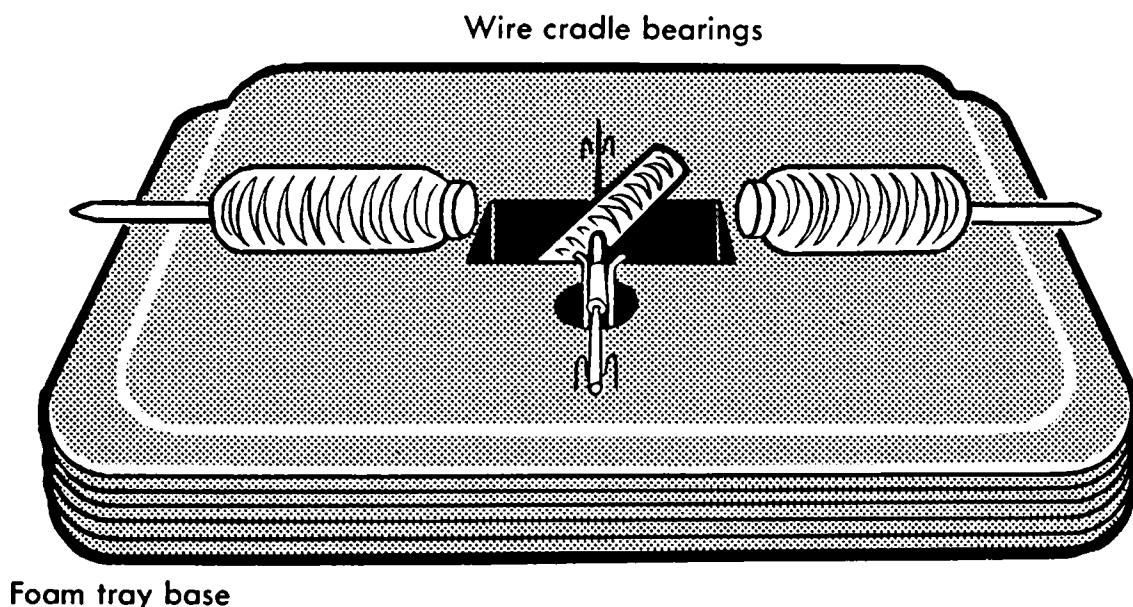


Plastic tumbler motor

Change to Long Stator Coils

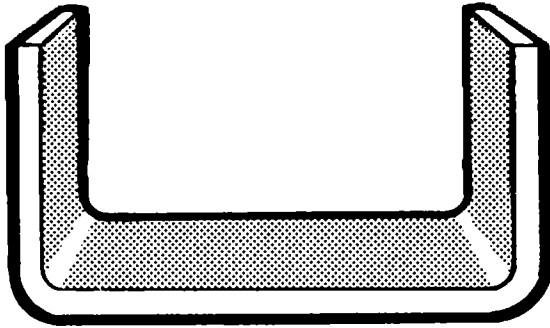
An interesting way to study long stator coils is to lay the electric motor on a long plastic foam base. This could be a foam block or, better still, four or five plastic foam meat trays glued together. Cut a slot in which the rotor can spin freely; drill a hole for the brushes. This hole can be drilled easily almost through the foam with a hot nail. Glue a cork underneath to the thin bottom below the hole to better support the brushes.

The coils can be moved freely on this base to study the relationship of magnetism and distance without taking time to secure them. If the coils have a tendency to roll because of the vibrations caused by a fast motor, tape them to the base. It always is wise to tape all loose wires while you have the tape in hand.



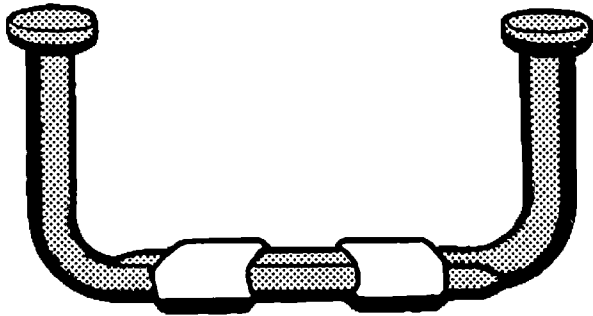
These stator coils can be changed quickly

Change the Core of the Stator Coil



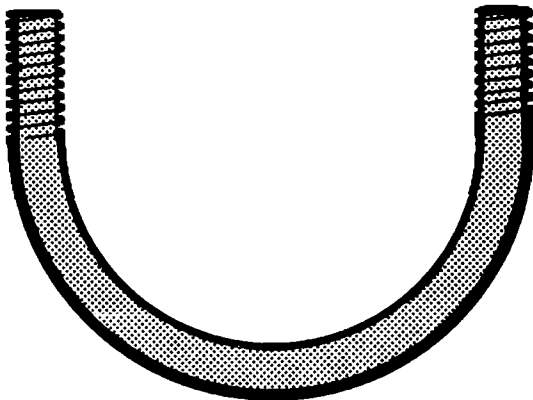
If I bend a soft iron bar into a U shape. . . .

Bent iron strap



If I bend two large nails and tape them together. . . .

Bent nails

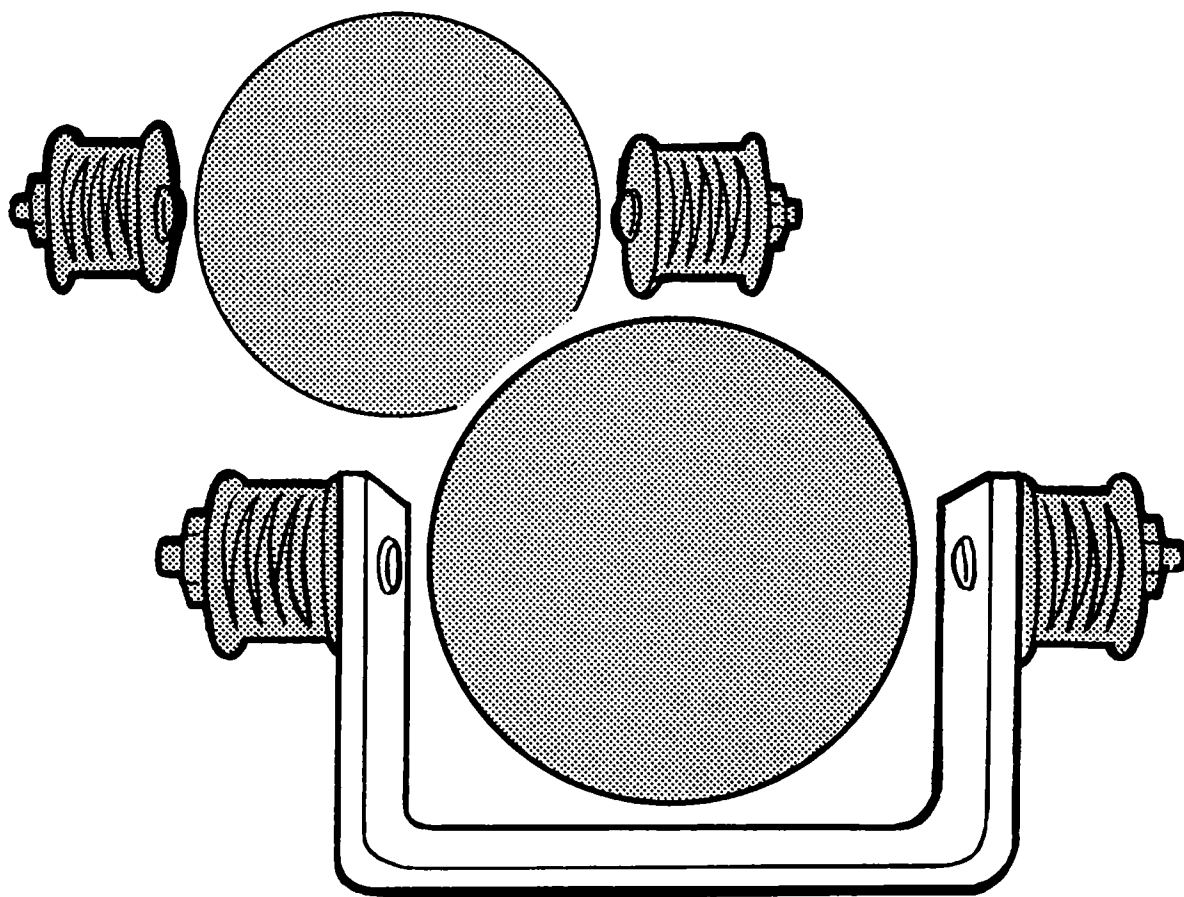


If I used a soft iron U bolt bought at the hardware store. . . .

“U” bolt

Change the Relationship of the Stators

Should the stators always be separate? Or would they work better if joined as one magnet? Use your compass, iron filings, and brads or tacks to find out which of these combinations produces the strongest stator or field magnets. How much iron should you use for the U-shaped core? Should the electromagnets be on the inside or the outside of the U bend?

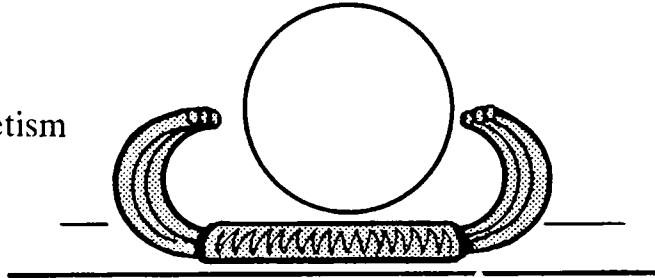


Always use the softest iron for cores

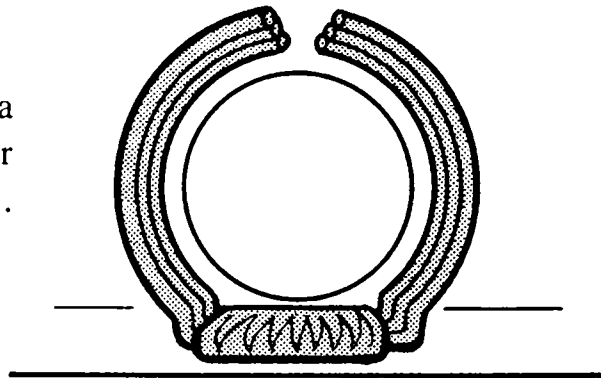
Change the Shape of the Stator Coil Core

All these cores can be bent from coat hanger wires, or they can be bent from soft iron bands. Forklift strap iron is easy to obtain at masonry shops or at lumber companies. Tin can metal has served well for many years.

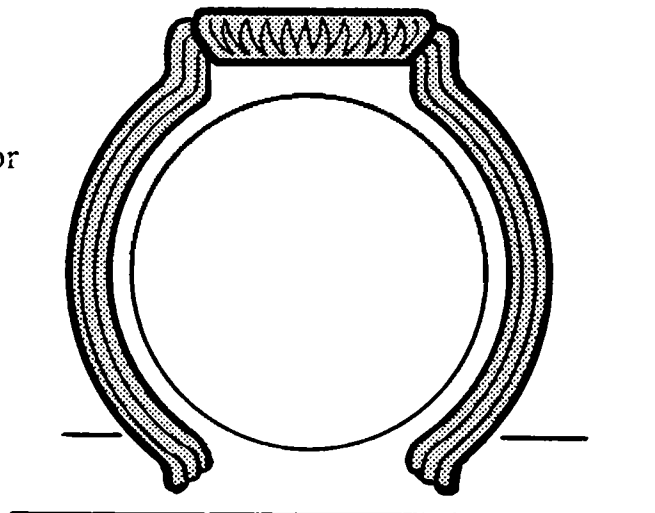
If I concentrated the magnetism in a specific region. . . .



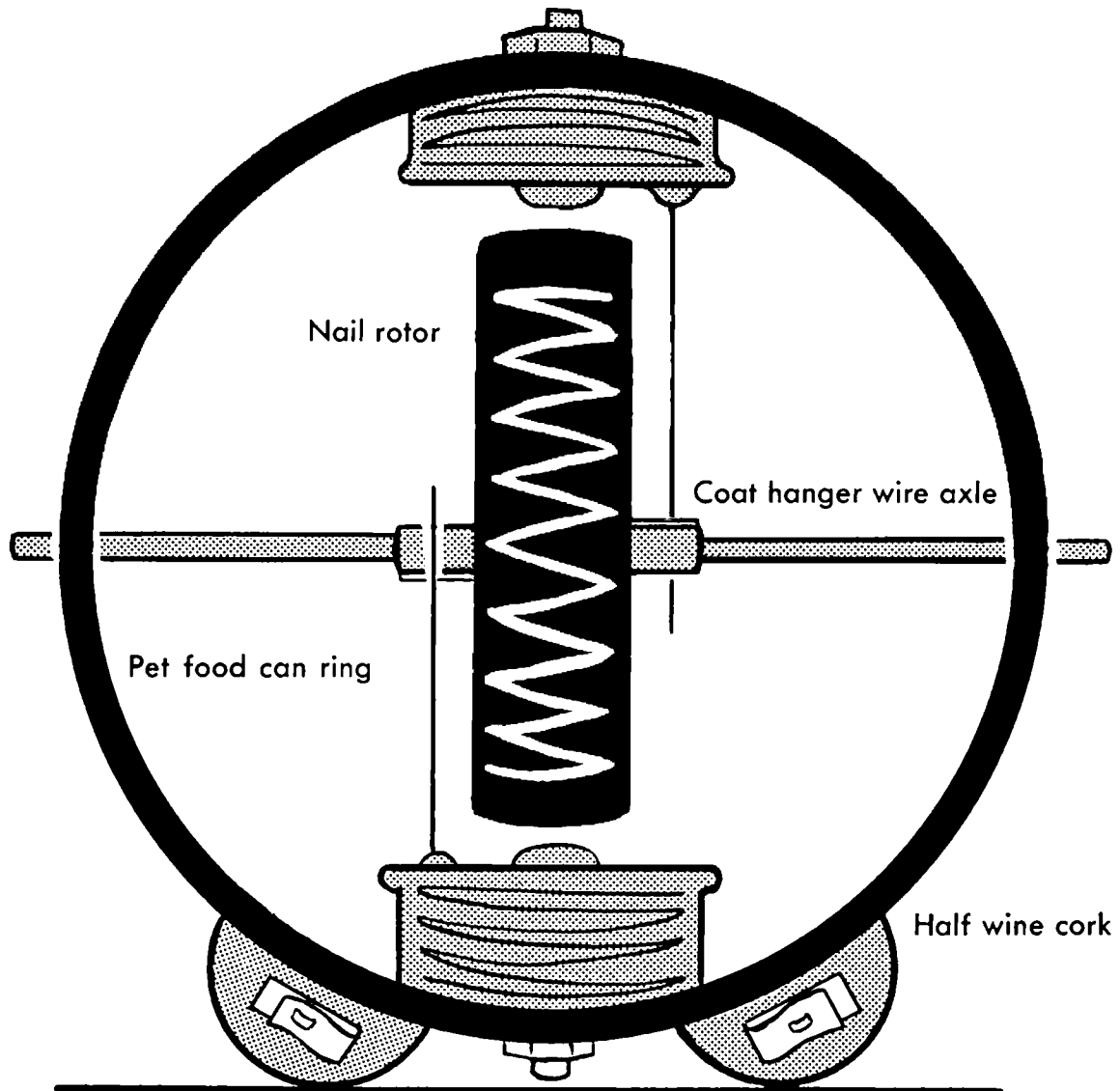
If I spread the magnetism over a wider area so that it would push or pull for a longer period of time. . . .



If I placed the coil above the rotor instead of below it. . . .



Change the Position of the Motor



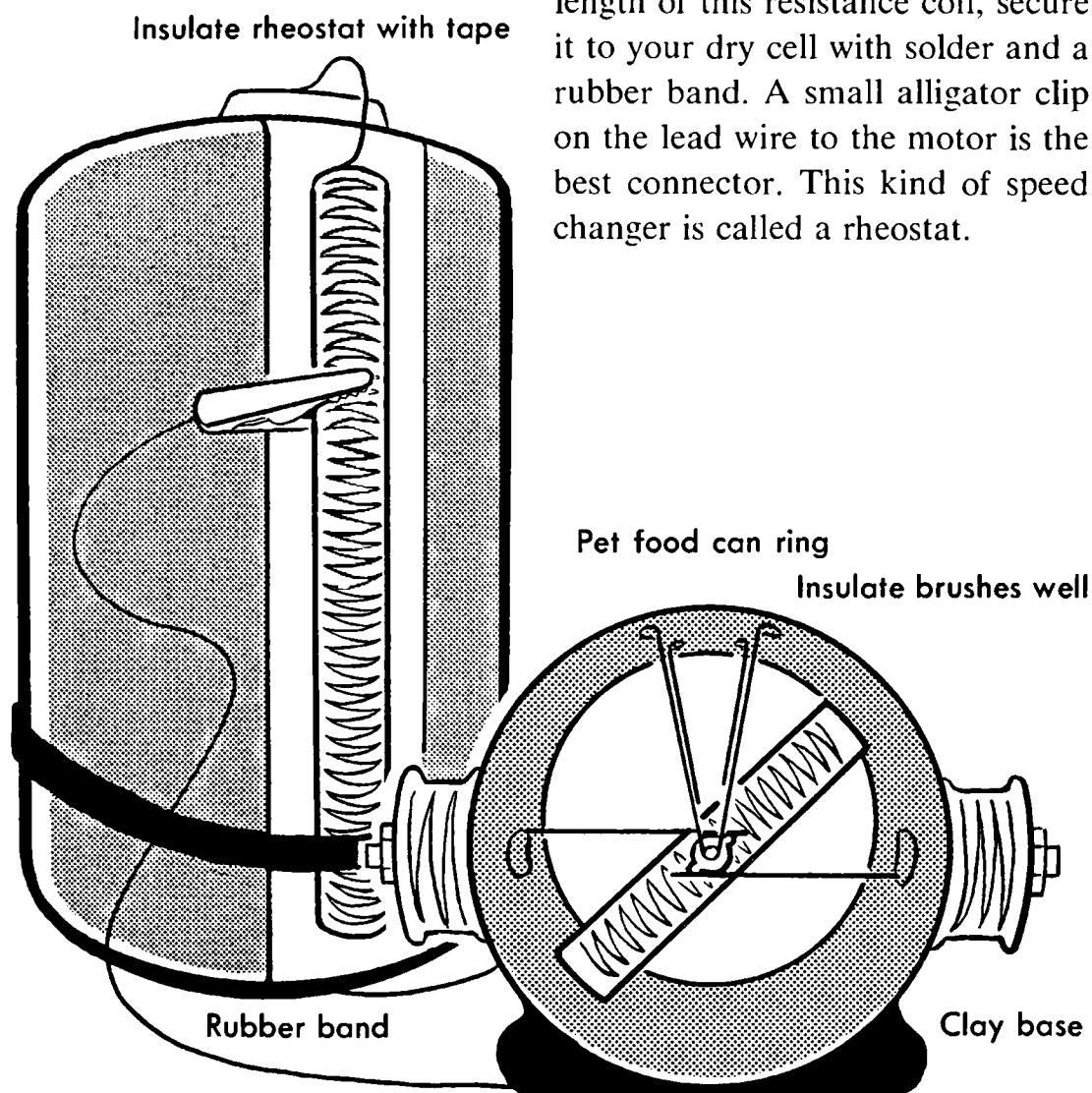
Pet food can motor

Why not run the axle horizontally through the ring of a pet food can? Secure the brushes to the cardboard coil forms with glue. Note that the brushes contact opposite sides of two commutators. The two halves of a wine cork glued to the ring form the base of the motor.

Challenge: Can you make a motor in which the axle and rotor stand still while the stator magnets and the frame spin around them?

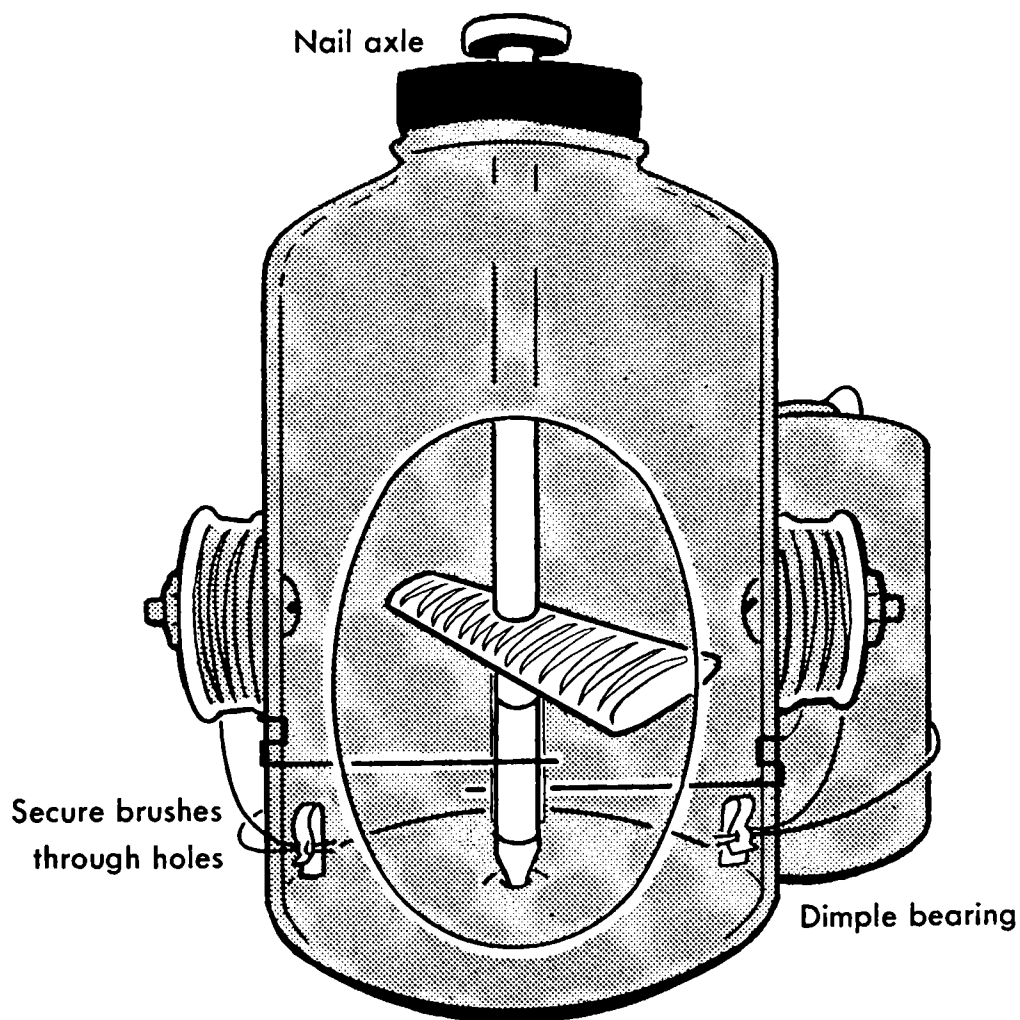
Change the Speed of Your Motor

The Maxi Motor is capable of going too fast for thin wire bearings. To control the speed of your rotor, get a 300-watt electric heater replacement coil from a hardware store. Experiment to find the best length for full speed control of your motors. When you find the ideal length of this resistance coil, secure it to your dry cell with solder and a rubber band. A small alligator clip on the lead wire to the motor is the best connector. This kind of speed changer is called a rheostat.



Rheostat speed changer

Change the Attitude of the Axle



Inside-the-bottle motor

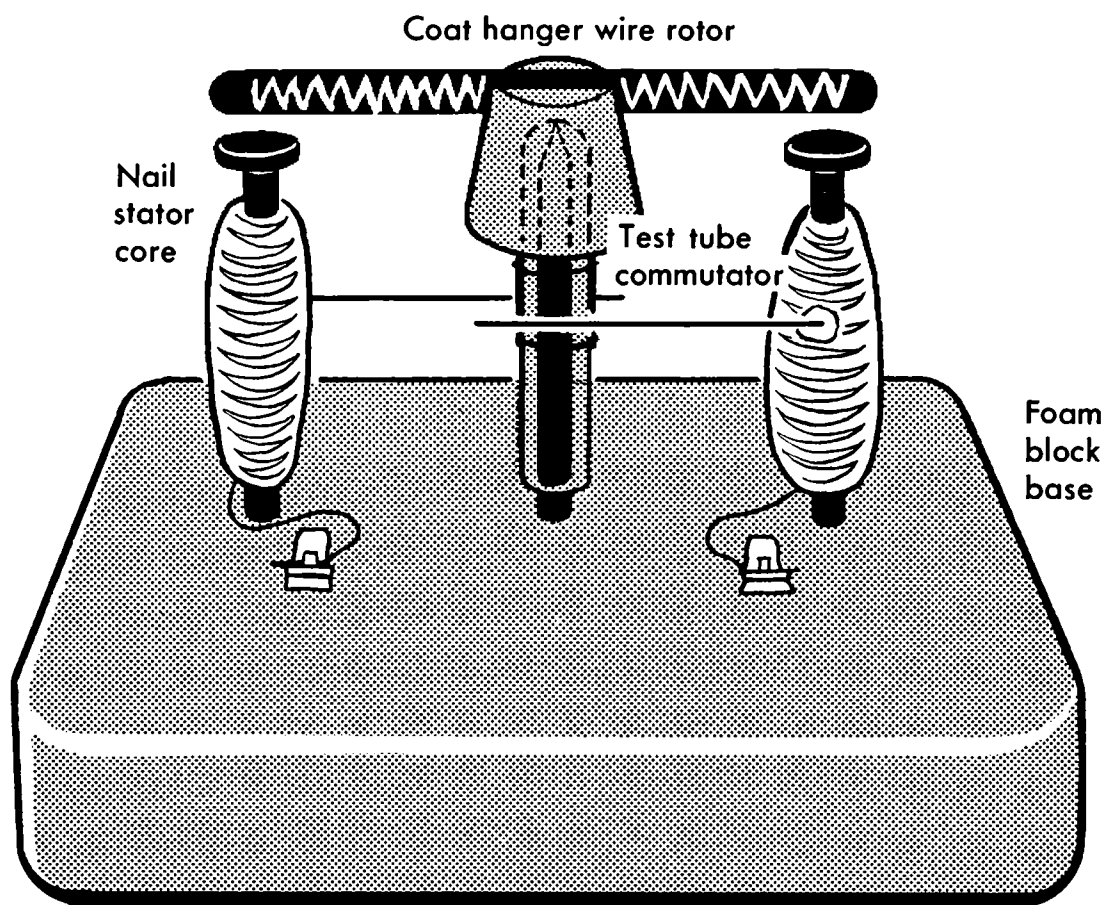
If some craftsmen have been able to build a ship in a bottle, you should be able to build a motor in a bottle. This is especially true if an egg-shaped hole has been cut into the front of a plastic bottle. Make the dimple for the bottom bearing by heating the end of the well-rounded axle and gently pressing it into the plastic. Bind the brushes tightly to the sides through double holes. Add glue to make them more secure.

Change the Attitude of the Axle

Should the rotor poles swing over the stator poles or in front of them? You be the judge after your motor indicates its preference to you.

Use a double bent coat hanger wire on the cork for a rotor core. The drilled cork can fit over a miniature test tube which straddles a nail driven upward through the base. A tape bushing should be added to the bottom of the nail to keep the test tube from vibrating.

The two ends of the rotor coil can be taped or tied and glued to the test tube to be used as a commutator. The bared upper ends of the stator coils can be glued to the sides of these coils to be used as brushes.

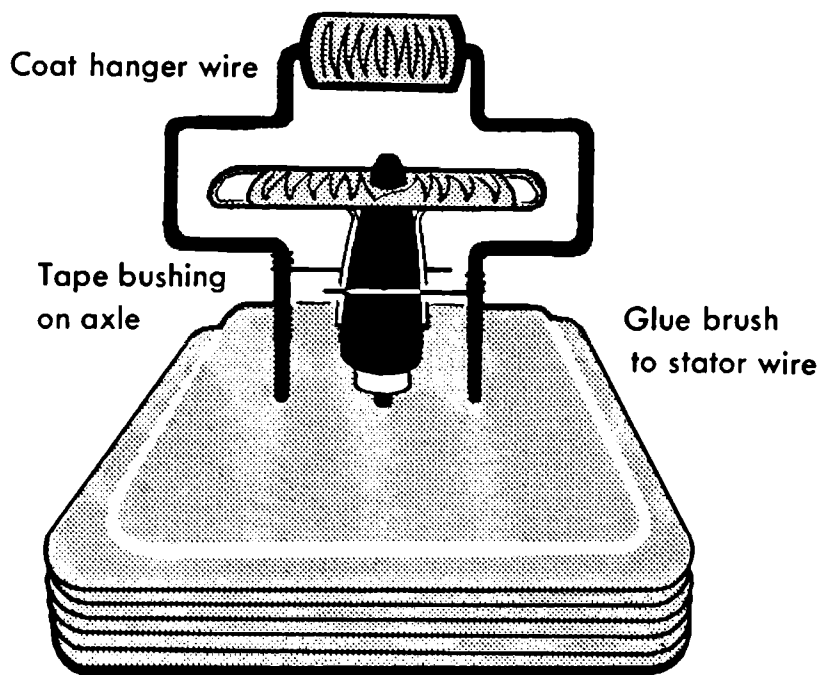


Cork-on-a-test-tube motor

Change the Attitude of the Axle

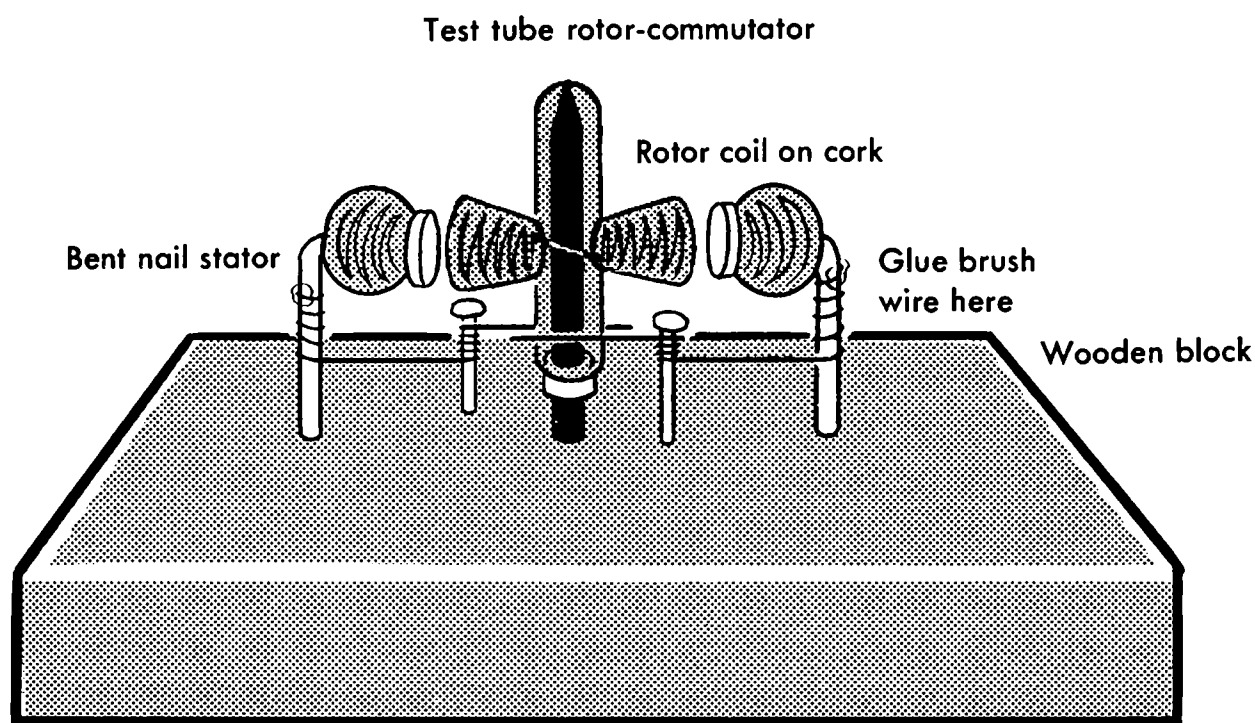
Press a jumbo-size paper clip over the cone of a pen top, and wrap the coil to make the rotor of this motor. The rotor will hang and spin on the vertical nail axle. Add a tape bushing to the bottom of the axle to keep the commutator from vibrating needlessly. Note how the brushes make use of the springiness of the coil winding. Glue the upper end of this coil to the coat hanger wire stator. Should the brushes be placed high or low? Your motor will tell you which is best.

Rotor is jumbo paper clip pressed onto pen top



Paper-clip-on-pen-top motor

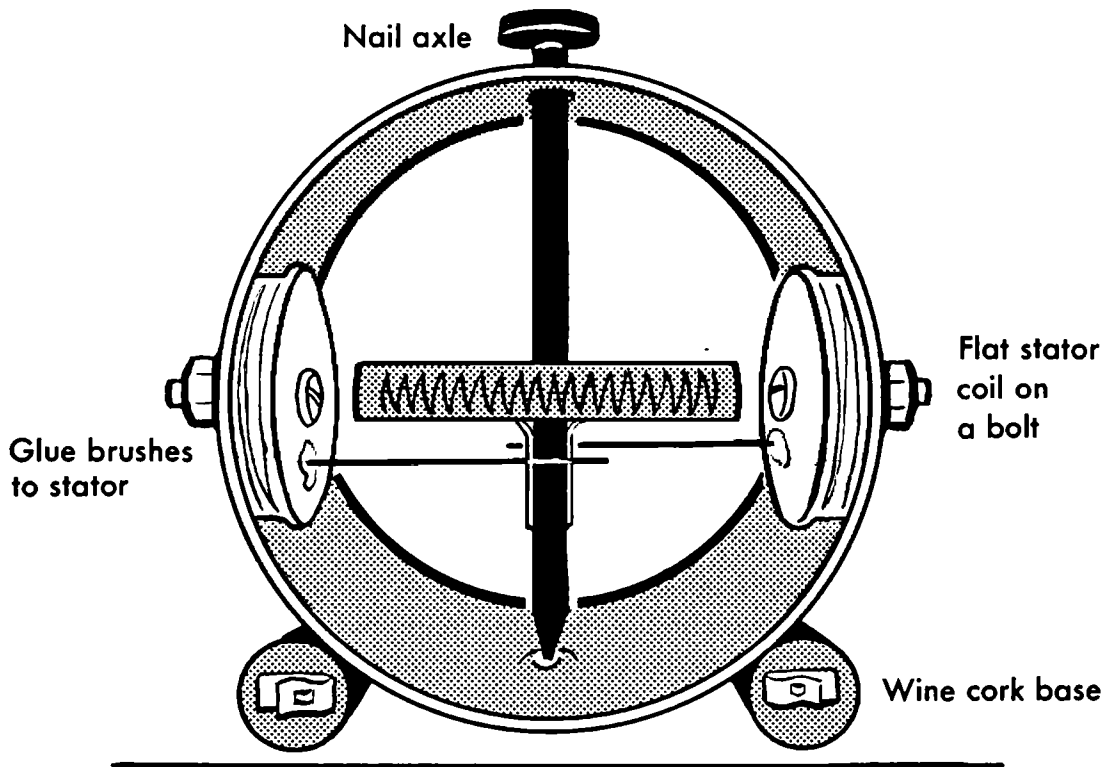
Change the Attitude of the Axle



Hanging-test-tube motor

The rotor of this motor is made by shaping the cork ends with sandpaper and gluing them to the sides of a small test tube. Would the motor work even better if small nails or brads were pushed inside each cork? Will the large nail used for the axle soak up too much of the magnetism? Would an aluminum nail or a plastic stirring rod make a better axle? Your motor will tell you.

Change the Attitude of the Axle

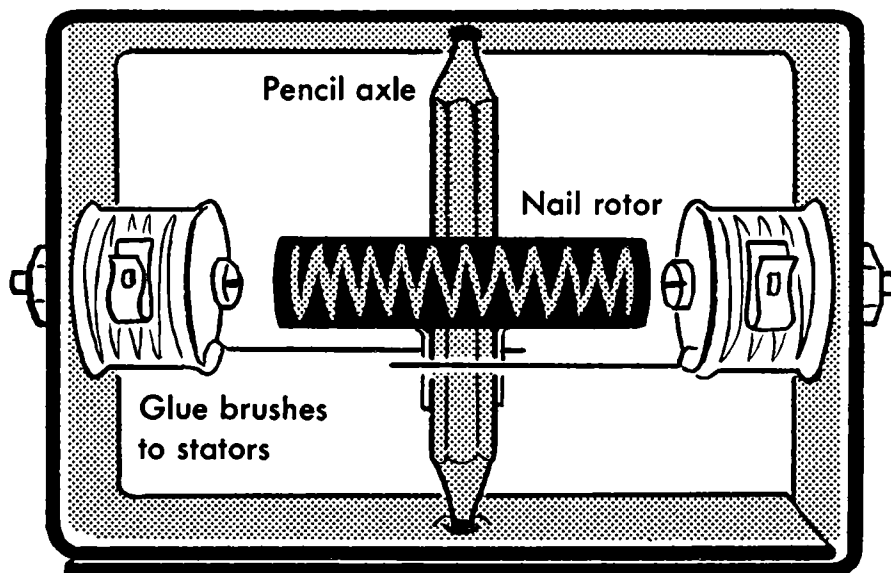


Plastic-ring motor

Make this motor inside a plastic bottle ring after cutting off the top and the bottom of the bottle. Wine corks can be glued, tied, or wired to the plastic ring to make a wide base. Glue Fahnestock clips to the corks to be used as power terminals. Use a dimple for the lower bearing. Glue brushes to the faces of the stator coils. Use fender washers to spread the influence of the stator poles.

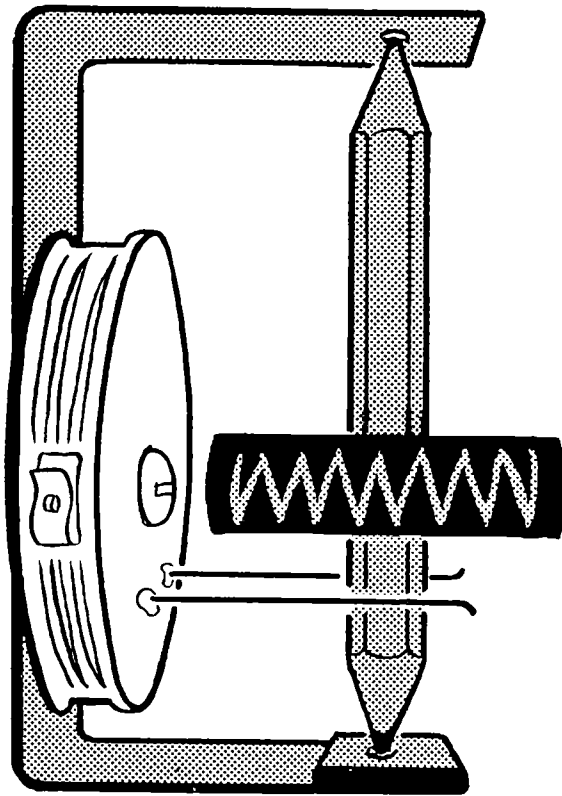
Change the Attitude of the Axle

Is a completely enclosed core better than two separate cores? Glue the brushes to the coil form or to the fender washers used to spread the stator poles. Have you tried brass wire brushes in place of the copper yet? The rotor coil core can be made of nails, coat hanger wire, or several jumbo paper clips. The stator core frame can be bent from a strip of bailing strap iron or from tin can metal. Notice how the base is overlapped so that the pencil axle can spin in the lower bearing hole without marking the table.



Rectangular motor

Change the Attitude of the Axle



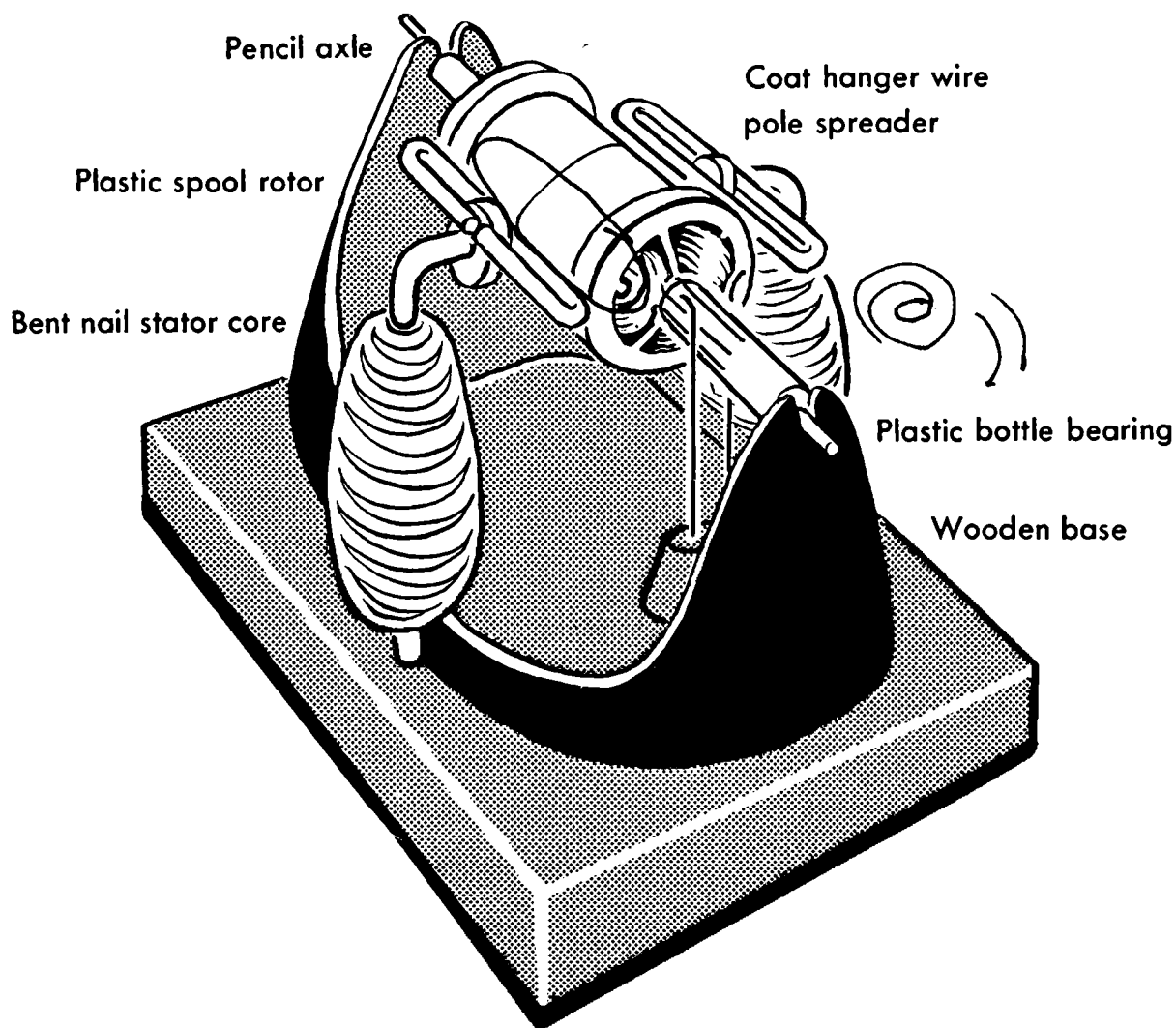
Sidesaddle motor

Make the U frame from the strap iron used for forklift bails. Glue the commutator wires to the sides of the pencil axle. Then be sure to scrape them clean of glue and varnish insulation on the contacting surface.

A Challenge for You

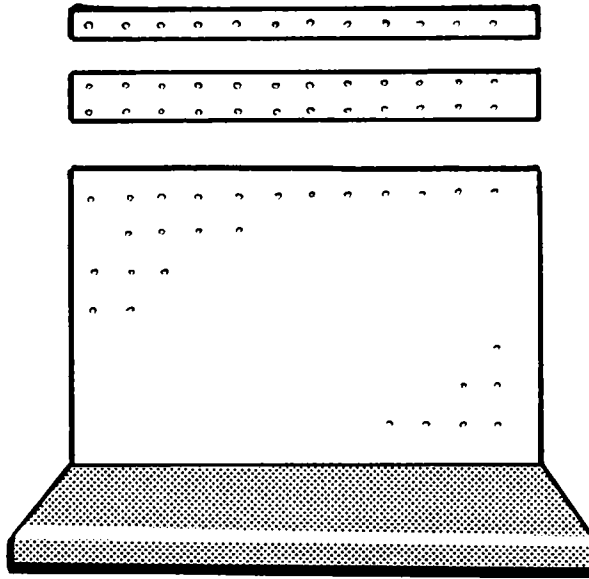
With all your experience, could you now build a motor with a three-coil rotor inside a plastic spool? Many small commercial toy motors have three rotor coils. What would be the advantages and the disadvantages?

Pencils just happen to fit most spools. And being six-sided, they provide two commutator surfaces for each of the three rotor coils. Or would the outside of the spool make a better commutator than the pencil? You should be able to predict, and your motor will tell you how right you are.



Triple-coil-rotor motor

Make Your Motors Work for You

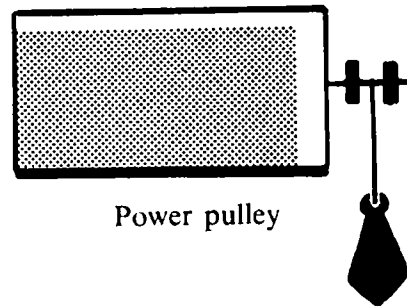


Experiment stand

A very useful experiment stand can be made from a square foot of punchboard. First, saw off two strips to be used as levers. Then nail or screw the larger piece of punchboard to a 6-inch-by-12-inch base board. Bolts, nails, and wire can be used to hold equipment to the stand. If punchboard is not available, plyboard can be used if you drill holes as you need them.

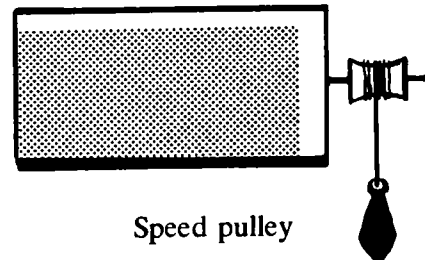
Adding a pulley to the end of the motor axle will enable your motors to do many things. The axle is your strongest power pulley. It may need guides to keep the thread in place. Larger guides can be sliced quickly from a cork and glued in place. Speed pulleys can be cut and shaped from large corks.

Motor



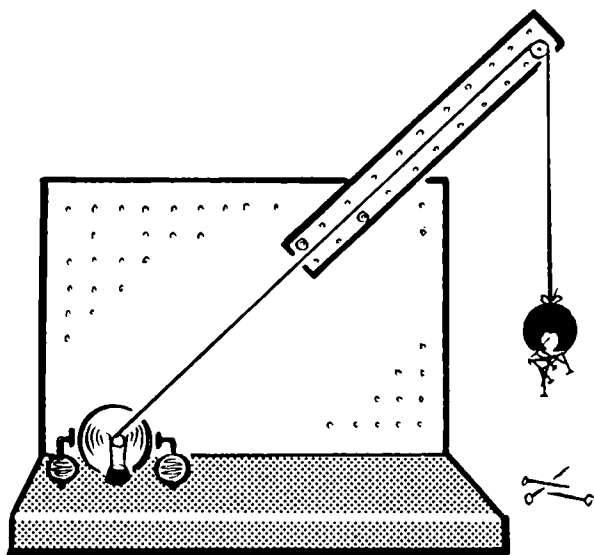
Power pulley

Motor



Speed pulley

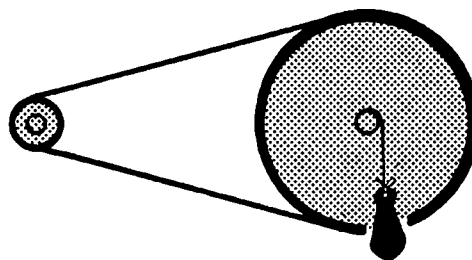
Make Your Motors Work for You



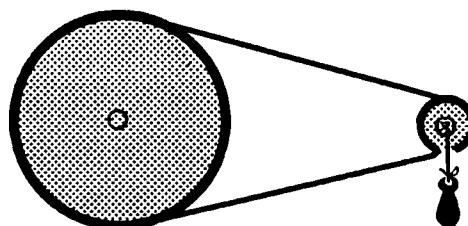
Magnetic crane

Pulleys are used to change speed and power. As a rule, if you increase speed, you will have less power. And when you increase power, you do it at the sacrifice of speed. But with wisdom you can change your pulleys to meet your needs. Pulleys can also be used to reverse direction by twisting the pulley belt.

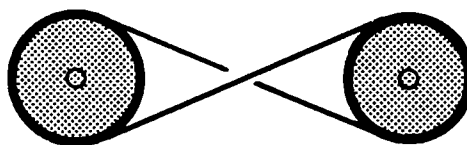
A cork pulley is easy to shape while it is spinning on the axle. Use a hacksaw blade and sandpaper. A spool pulley works well when secured tightly to the axle with a masking tape bushing. You should know the difference between a power pulley and a speed pulley to get the best use of your motors. Use a wide rubber band for the pulley belt.



Power pulley



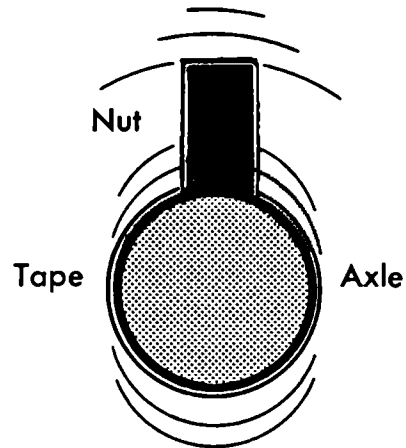
Speed pulley



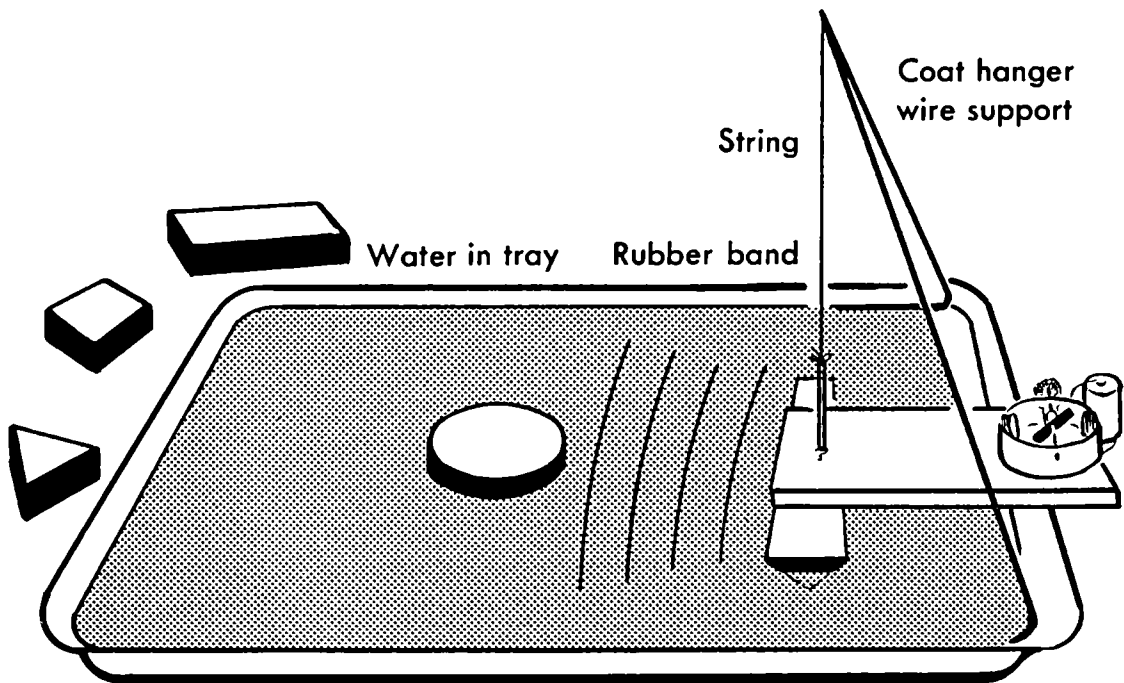
Reverse pulley

Make Your Motors Work for You

This simple wave generator depends on a small off-center weight such as a square nut from a bolt. This extra weight on one side of the axle will vibrate the motor and the floating board to generate the waves. Change the waves by moving the motor forward and backward on the board, by increasing or decreasing the amount of eccentric weight, and by using your resistance-coil rheostat. Use a pan of sand to study wave effects on model beaches, harbors, and islands:

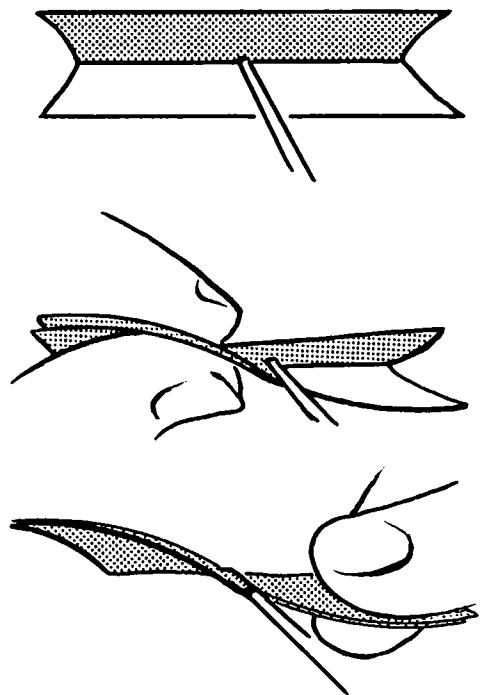


Off-center weight on axle causes waves



Wave generator

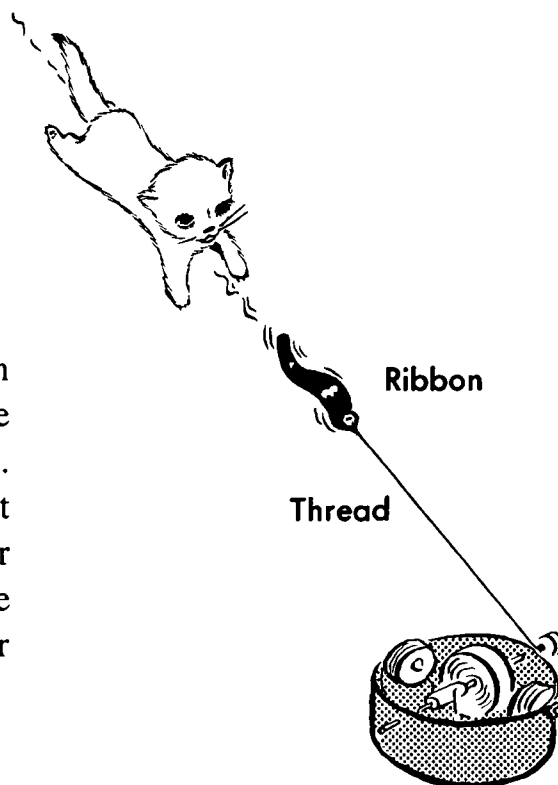
Make Your Motors Work for You



Bending an airplane propeller

A fine centrifugal fan can easily be made by folding and sticking a piece of masking tape to the axle. An airplane propeller is made by bending the blades at an angle to provide pitch before sticking them together. These can be laminated with several layers of tape to add strength. Could you make a paper helicopter blade on a soda straw that could take off from a motor with a standing axle?

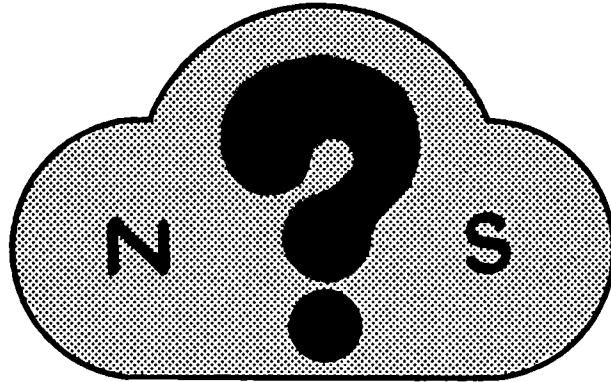
Your kitten will love you even more if you exercise it with the feline fascinator shown at the right. Tie a ribbon, yarn, or lightweight toy to a thread and let your motor pull it across the room. The more it skips and bounces, the more your kitten will like it.



Feline fascinator

5

The Super Motor



This motor will be of your own design. Put together all the best features, the best properties, and the best conditions of all the motors you have made. The result will be your Super Motor.

The Super Motor

Now you are on your own. This chapter has no illustrations to guide you, and there are no suggestions for starting experiments. As you experimented with the three basic motors and their variations, you probably liked some features better than others. Some materials were easier for you to obtain. You developed certain skills with your own tools. Now you can combine all the best ideas in your very own design for a Super Motor.

You will want to put the best of everything together. But first, you must honestly say to yourself, "Best for what?" Do you want a speedy motor or a powerful motor? Do you really have room enough for a big motor? Or should it do a very special job in a small space? Should it be rugged and almost indestructible? Or will it be protected? Will it get wet? You must decide first the job this motor is to do for you. Then you can build the properties and conditions into the motor which will do that job best.

Remember that you can experiment with your Super Motor as you build it. When you decide that you have the best of everything together, you can close the bearings, fasten all the loose wires, and solder all circuit connections securely. A working motor looks different from an experimental model. Go ahead with your own Super Motor.

INDEX

- Alnico bar magnets, 8, 10
- Armature, 8. *See also* Rotor
- Axle
 - changing, on maxi motor, 103–4
 - changing, on midi motor, 73
 - changing, on mini motor, 40–42
 - changing attitude of, on maxi motor, 112–18
- Bar magnets, Alnico, 8, 10
- Base
 - changing, on maxi motor, 97
 - changing, on midi motor, 67
 - changing, on mini motor, 26–30
 - making, on maxi motor, 87
 - making, on midi motor, 56
- Bearings
 - adding, on midi motor, 57
 - bending, on mini motor, 22
 - changing, on midi motor, 72
 - changing, on mini motor, 46–47
 - making, on maxi motor, 87
- Brushes
 - building, for maxi motor, 88
 - changing method of securing, on maxi motor, 96
 - changing method of securing, on midi motor, 78
 - changing shape of, on midi motor, 79
 - placing, on midi motor, 58
- Cell connections, changing, on mini motor, 33–35
- Circuit
 - on maxi motor, 93
 - on midi motor, 61
- Clip leads, 66
- Coil. *See* Rotor coil; Stator coil
- Commutator
 - adjusting, on midi motor, 62
 - building spinning switch, for maxi motor, 90
 - changing, on maxi motor, 99
 - changing diameter of, on midi motor, 75
 - changing end-view shape of, on midi motor, 77
 - changing material of, on midi motor, 74
 - changing placement of, on midi motor, 76
- Commutator surface, changing, on maxi motor, 98
- Cradle bearings, 22
- Experiments
 - making motors work, 119–23
 - with magnets, 14–15, 16
 - with maxi motors, 95–118
 - with midi motors, 65–84
 - with mini motors, 25 ff.
- Field coil. *See* Stator coil
- Field magnet, 8. *See also* Stator magnet
 - binding, on mini motor, 21
- Filing system, starting, for motor parts, 37
- Hot-pad magnets, 9
- Magnetic sculpture, 17
- Magnets, 8
 - finding polarity of, 10
 - gluing, on midi motors, 55
 - how they work, 13–17
 - marking, 11
- Materials, 9
- Maxi motor, 7, 85–111
 - changing position of, 110
 - changing speed of, 111
 - checking for polarity reversal, 94
 - circuit, 93
 - definition of, 85–86
 - experiments with, 95–118
 - how to build, 85–95
 - balancing rotor, 92
 - building brushes, 88
 - building spinning-switch commutator, 90
 - making base and bearings, 87
 - making rotor, 89
 - winding stator coil, 91
- Midi motor, 7, 53–85
 - commutator, adjusting, 62
 - circuit, 61

- definition of, 53
- experiments with, 65–84
- how to build, 54–65
 - adding bearings, 57
 - adding power, 60
 - gluing magnets, 55
 - making foam base, 56
 - placing brushes, 58
 - placing rotor, 60
 - winding stator coils, 59
- polarity, checking, 64
- timing, testing, 63
- Mini motor, 7, 18–52
 - changing size of, 52
 - definition of, 18
 - experiments with, 25–52
 - how to build, 18–19
 - adding power, 24
 - balancing rotor coil, 23
 - bending bearings, 22
 - binding stator magnet, 21
 - winding rotor coil, 20
- Motors,
 - materials for building, 8–9
 - types of, 7
- Polarity
 - checking, on midi motor, 64
 - finding, of magnets, 10
- Polarity reversal, checking for, in rotor magnet, 94
- Power supply, changing, on mini motor, 31–32
- Pulleys, 120–21
- Rotor, 8, 18
 - balancing, on maxi motor, 92
 - changing material of, on midi motor, 68
 - changing to nonmagnetic, on midi motor, 84
 - changing position of weight on maxi motor, 101
 - changing position of weight on mini motor, 45
 - changing weight, of, on mini motor, 43–44
 - making, for maxi motors, 89
 - placing, on midi motors, 60
- Rotor coil
 - balancing, 23
 - changing attitude of, on maxi motor, 100
 - changing position of, on maxi motor, 102
 - changing shape of, 36
 - winding, on mini motor, 20
- Rotor magnets
 - changing attitude of, on midi motor, 71
 - changing number of, on midi motor, 69
 - changing position of, on midi motor, 70
 - checking for polarity reversal in, 94
- Spinning-switch commutator, building, for maxi motor, 90
- Stator coil
 - changing attitude of, on mini motor, 39
 - changing core of, on maxi motor, 107
 - changing core of, on midi motor, 80
 - changing number of, on midi motor, 81
 - changing number of turns of, on midi motor, 82
 - changing number of turns of, on mini motor, 38
 - changing to long, on maxi motors, 106
 - winding, on maxi motor, 91
 - winding, on midi motor, 59
- Stator magnet, 8, 18
 - binding, on mini motor, 21
 - changing, on maxi motor, 105
 - changing, on mini motor, 51
 - changing position of, on mini motor, 48
 - changing relationship of, on maxi motor, 108
 - changing shape of, on mini motor, 50
 - changing strength of, on mini motor, 49
- Super motor, building, 7, 124–25
- Switch, protecting cells with, 35
- Timing, testing, on midi motor, 63
- Wave generator, 122
- Wire, changing size or gauge of, on midi motor, 83

The Author

AL G. RENNER is the author of *How to Make and Use a Micro-lab*, a popular book from Putnam's. He is a science consultant and teacher-training instructor for several school districts in the Los Angeles area. Since graduating from the University of Southern California, Mr. Renner has spent most of his time either teaching science or teaching teachers to teach science. He and his wife live in Altadena.

The Author

AL G. RENNER is the author of *How to Make and Use a Microlab*, a popular book from Putnam's. He is a science consultant and teacher-training instructor for several school districts in the Los Angeles area. Since graduating from the University of Southern California, Mr. Renner has spent most of his time either teaching science or teaching teachers to teach science. He and his wife live in Altadena.

7401

G. P. PUTNAM'S SONS
Publishers Since 1838
200 Madison Avenue
New York, N.Y. 10016

PRINTED
IN
U.S.A.

SCIENCE PROJECT BOOKS FROM PUTNAM

HOW TO MAKE AND USE A MICROLAB

by Al G. Renner

YOUR SCIENCE FAIR PROJECT

by William Moore

HERE IS YOUR HOBBY: SCIENCE EQUIPMENT

*Easy-to-make items for
the home science laboratory*

by William Moore

HOW TO MAKE AND USE ELECTRIC MOTORS

by Al G. Renner